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THE DEVELOPMENT OF THE COILED-COIL LAMP

By W. GEISS.

Summary. The coiled-coil filament, while emitting the same luminous energy, transmits less heat to the surrounding gas envelope than the single-coil filament. As a result coiled coils give a marked increase in efficiency, especially with lamps of low rating.

One of the primary aims of the electric lamp industry is to produce sources of light which will convert electrical energy into useful light with the maximum efficiency. In the pursuit of this goal two different methods of approach have been followed during the last ten years. On the one hand entirely new sources of light have been evolved, such as gaseous discharge lamps, in reference to which several articles have already appeared in this Review. On the other hand, systematic investigations have been carried out into all possible means for improving the efficiency of existing types of electric lamp. In this direction also, considerable progress has been made, for instance by the production of the coiled-coil lamp, which was placed on the market about two years ago. Some details of the investigations which led to the design and manufacture of this new lamp are described below.

The efficiency of an electric incandescent lamp increases with the temperature of its filament, but this gain is obtained at the cost of the life of the lamp since the rate of volatilisation of the filament also increases considerably with the temperature. In endeavouring to obtain a high efficiency it is of primary importance to keep the rate of volatilisation as low as possible, or, what comes to the same thing, to obtain the highest temperature for a given rate of volatilisation. This end may be attained in two ways:

1) By the discovery of a substance which volatilises very slowly, and

2) By the introduction of a gas filling.

The original material used for lamp filaments was carbon (carbonised bamboo fibre), which was later replaced by graphite. A further increase in temperature was made possible by the adoption of metals with high fusion points, viz, osmium, tantalum and tungsten. Developments in this direction have now provisionally terminated with the general use of tungsten, but it is not impossible that certain metallic oxides and nitrides volatilise still more slowly than tungsten, although up to the present no success has attended the attempts to produce sufficiently homogeneous filaments from these substances. Tungsten thus remains without dispute the best material for lamp filaments.

The most important properties of tungsten fila-

ments are collated in *Table I*. If a life of 1000 hours is required, an efficiency of about 10 lumens per watt may be obtained with a filament 0.01 mm thick. With a filament 0.1 mm in thickness an efficiency of about 13 lumens per watt can be obtained under equivalent conditions. These values apply to straight filaments in vacuo.

Table I. Life of an incandescent straight-wire tungsten filament as a function of the temperature. The mean life is related to the rate of volatilisation by the experimental fact that during the normal mean life 10 per cent of the mass of the filament volatilises. (Taken from C. Zwikker, Physica **5**, 252, 1925.)

Absolute temperature	Efficiency	Rate of volatilization	Life of a filament 0.01 mm in diameter	Life of a filament 0.01 mm in diameter
°K	lumens/watt	gr/cm² sec.	hours	hours
2000	2.93	$15.5 \cdot 10^{-15}$	$1.04 \cdot 10^{7}$	$1.04 \cdot 10^{8}$
2200	5.71	$22.4 \cdot 10^{-13}$	$7.20 \cdot 10^{4}$	$7.20 \cdot 10^{5}$
2400	9.77	$13.8 \cdot 10^{-11}$	$1.17 \cdot 10^{3}$	$1.17 \cdot 10^{4}$
2600	14.8	$41.7 \cdot 10^{-10}$	38.6	386
2800	20.9	$83.3 \cdot 10^{-9}$	1.9	19
3000	27.8	$10.5 \cdot 10^{-7}$	0.15	1.5

The effect of a gas filling on the rate of volatilisation may be discussed from *fig. 1*. Consider the filament to the left of the vertical line. A tungsten atom on volatilising will in the first place move towards the right. After a few collisions with the gas molecules the atom will have lost its initial energy, and it will then depend on fortuitous circumstances whether the atom will now turn back in its path or continue to travel away from the filament. Half the atoms will do the one thing and the other half the reverse. In consequence of further collisions with gas molecules this alternative will repeat, when the tungsten atom has travelled a certain path. It is seen from *fig. 1* that only a small fraction of the atoms reach the opposite wall. In the case illustrated with two plane walls at a distance of five of these paths apart, the rate of volatilisation will be reduced to a fifth. *Fig. 2* gives a diagram of the reduction of volatilisation which is obtained with a tungsten filament 75 μ in diameter. It is seen that the rate of volatilisation decreases to a few per cent of its original value by a filling of argon or nitrogen at 50 to 100 cm pressure.

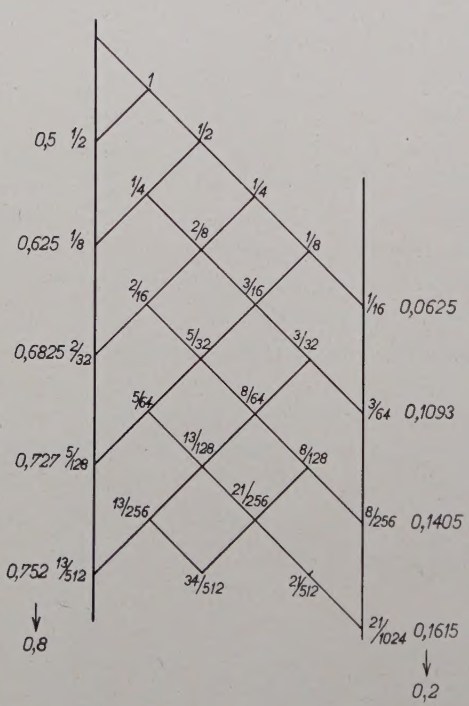

Fig. 1. Diagrammatic representation of the diffusion of atoms through a gas. In consequence of collisions with the gas molecules the atoms emitted from the plate at the left are able, after a certain path, to choose a direction either to the right or to the left. With the plates at a distance of five of these paths apart, only a fifth of the atoms emitted reaches the right-hand plate.

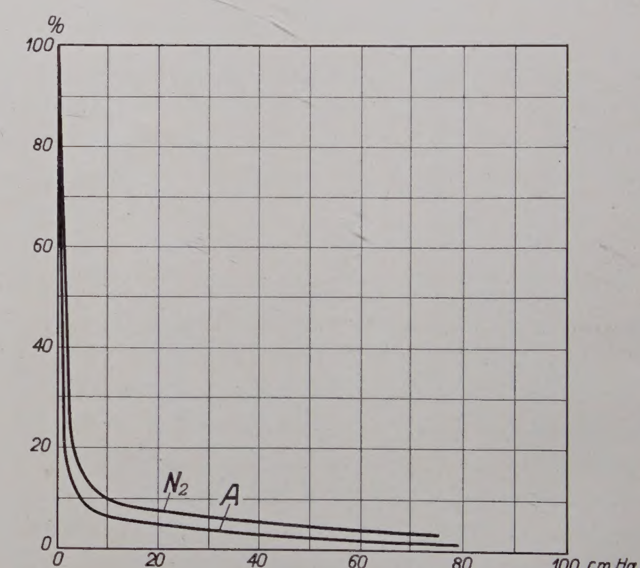

Fig. 2. Rate of volatilisation of incandescent tungsten filaments in atmospheres of nitrogen and argon respectively, plotted against the gas pressure.

Unfortunately a gas filling also introduces a disadvantage, for the thermal conduction and convection of the gas causes additional losses which in the case of thin straight filaments may in fact be greater than the gain obtained by the increase in temperature. Thick filaments in this respect give much more satisfactory values than thin ones. Experience has shown that the loss of heat due to the presence of the gas increases but little with increase in filament diameter, while radiation is proportional to the diameter. In other words, at a

given radiation output the losses due to thermal conduction increase almost proportionally to the length of the filament. L a n g m u i r, who was the first to call attention to this remarkable phenomenon, advanced the following explanation. Convection currents are set up in the hot gas surrounding the filament. The latter is itself, however, surrounded by a film of gas, which remains at rest since its viscosity owing to its high temperature is very high (cf. *fig. 3*). The thickness of the stationary film is determined by convection currents along the outer wall of the cylinder and is only slightly dependent on the diameter and temperature of the very much thinner filament.

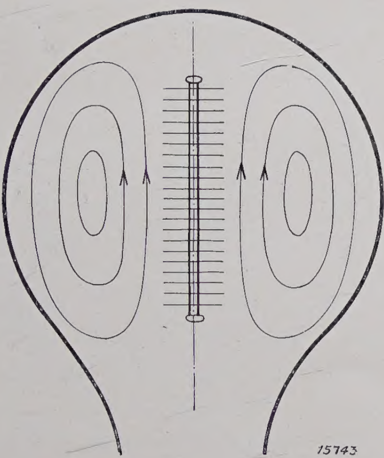

Fig. 3. The incandescent filament is surrounded by a stationary film several millimetres in diameter. Outside this layer the convection currents in the gas ensure uniform temperature distribution. The heat dissipated is, however, restricted by the thermal conductivity of the layer of stationary gas.

The energy losses are due to thermal conduction through the film of stationary gas and with a constant thickness of the layer they are proportional to the length of the filament.

In former years investigations have been proceeding at this laboratory with respect to the thermal conduction of incandescent filaments, and these investigations have shown very clearly the action of the stationary layer. Two similar incandescent tungsten filaments were suspended side by side in an atmosphere of argon at 60 cm pressure, using a holder by means of which the distance between the wires could be altered at will. Curves *S* and *C* in *fig. 4* show the heat losses due to radiation and conduction as a function of the distance between the filaments, the temperature being constant. While radiation is practically constant, the conduction factor diminishes very considerably as soon as the stationary films of the two filaments overlap. At a very small distance apart, conduction (curve *C*) is only half the initial value, while the radiation loss (curve *S*) has barely altered. The two filaments are then surrounded by a common layer of stationary gas so that the effective length of the filament is reduced to half.

The heat losses through conduction are particularly important in the case of small lamps. The

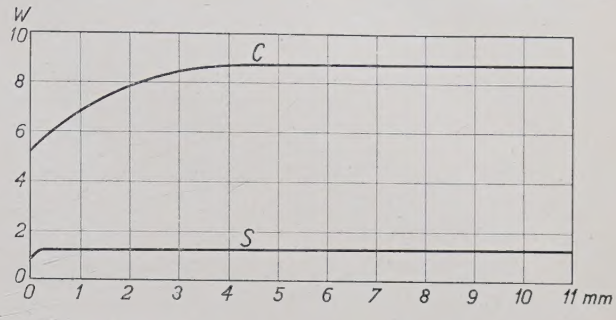

Fig. 4. Heat losses from two incandescent filaments as a function of their distance apart.
S By radiation.
C By conduction and convection of the gas filling.
The heat transfer to the gas is considerably diminished when the filaments are brought so close together that the stationary layers overlap. On the other hand radiation is practically independent of the distance between the filaments.

lower the rating of the lamp the thinner are the tungsten filaments, and hence the smaller the radiation emitted per unit of length as compared with the heat losses.

An important advance was made in the design of small lamps, by the introduction of the coiled-coil filament. If a long thin filament is wound in the form of a spiral or coil, its total heat losses are of the same order as for a filament with the same length and cross-section as the coil. In this way the effective overall length of the filament can be considerably reduced, the reduction becoming the greater the greater the diameter of the coil.

The diameter of the coil cannot, however, be indefinitely increased, for with increasing diameter the resistance to deformation of the coil diminishes to such an extent that there is a danger of short circuits occurring between the turns when exposed to unavoidable shocks and vibrations. Nevertheless it has been possible to reduce the effective length of the coil still further by winding the coil itself round a core and thus arriving at a coiled-coil arrangement.

The first attempts to use coiled coils were already carried out about 20 years ago, but these failed owing to the inadequate processes for manufacturing the coiled-coil filament. The incandescent elements made at that time possessed the undesirable property of expanding during service so that the coil of an old lamp showed a marked sag.

Extensive research on tungsten wires and filaments which were worked cold and hot by various processes, showed that the sag f of the filaments could be expressed as a function of the time t, as follows:

$$f = a_1 + a_2 t^b \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The initial sag a_1 is produced when the filament is firstly raised to its incandescent temperature and is largely independent of the pre-treatment of the coil. By suitable pre-treatment it is, however, possible to reduce the value of the exponent b very considerably. Finally the initial sag a_1 can be widely reduced, by submitting the finished coil to prolonged heat treatment at a high temperature so that it assumes a suitable crystal structure. To prevent expansion of the filament already during this heat treatment it has been found necessary to use for the core a material with a high melting point. The primary and secondary coils are wound on molybdenum cores, which after heat treatment are removed from the coils by chemical means. *Fig. 5* showing the filaments of a modern lamp and of an old one (both after about 1000 hours' burning) indicates the progress which has been made in the course of the last few years in stiffening the coils. This improvement is also shown quantitatively in *fig. 6*. These illustrations show clearly that it is now no longer possible to estimate the age of a lamp from the sag of the filament, even in lamps with single coils which have also shared in the advances made in filament-finishing processes.

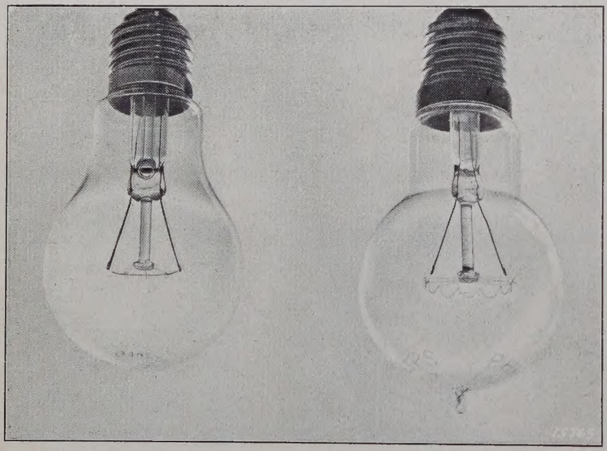

Fig. 5. A lamp with non-sagging coiled-coil and another with a sagging single coil, both after about 1000 hours' burning. It is clear that nowadays no conclusion can be drawn from the sag as regards the age of the lamp.

A mixture of argon and nitrogen has been used for filling coiled-coil lamps as was employed for single-coil lamps also. As both the heat losses and the rate of volatilisation diminish with increasing atomic weight of the filling gas, an examination of the properties of the heavier rare gases suggested itself. This work has only been made possible in recent years after technical methods had been evolved for isolating krypton and xenon in such quantity and of such purity as to permit comprehensive experiments on a technical scale [1]).

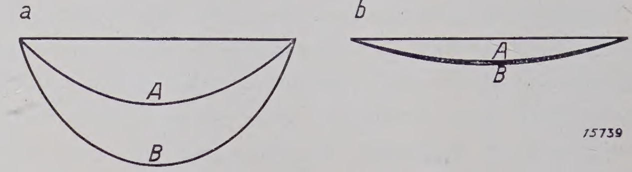

Fig. 6. The depth of sag f is related to the hours of burning by the equation: $f = a_1 + a_2 t^b$. The figure shows the sag: A after 1 hour, B after 500 hours.

a) Sagging filament: $a_1 = 0.08$, $a_2 = 0.08$, $b = 0.150$

b) Non-sagging filament: $a_1 = 0.00$, $a_2 = 0.08$, $b = 0.005$

A marked diminution in the factors investigated was actually found with these gases, the rate of volatilisation in krypton being only half that in argon under the practical conditions in question here. The heat losses were also much lower, as may be seen from the example quoted in *Table II*.

Table II. Heat losses due to gas Filling.

Gas	Per cent Heat losses
Argon filling	100
Krypton filling	68
Xenon filling	53

In spite of these advantages, the substitution of an expensive krypton filling for argon does not at the present time appear practicable. Whether such substitution may be possible in the future depends on what progress is made in the isolation of the rare gases.

A further novelty of the coiled-coil lamp is that each lamp is supplied with its own self-contained fuse. This has been done because the break-spark produced when the lamp blows may strike an electric arc between the electrodes. The internal fuse then blows and thus protects the mains fuses.

[1]) Krypton and xenon are constituents of the atmosphere. 1 cub.m of air contains about 10 ccm of krypton and 1 ccm of xenon.

The semi-frosting frequently used hitherto has been replaced by internal frosting in the coiled-coil lamp, since it has been possible to reduce the absorption of light with the latter to below that with semi-frosting; the light loss is now only 0.5 to 1 per cent as compared with 2 per cent for semi-frosting. Moreover, from the point of view of illuminating engineering semi-frosting is incorrect, since it acts as a reflector so that 60 per cent of the light is reflected upwards and only 40 per cent is thrown downwards. In the diagram of flux distribution *(fig. 7)* the difference between these two methods of frosting in clearly shown.

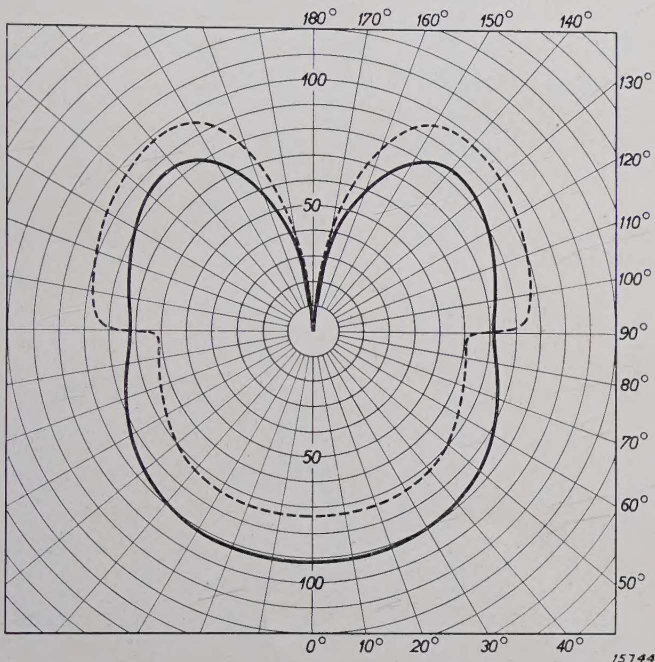

Fig. 7. Diagram of light distribution for a internally-frosted lamp (continous line) and a semi-frosted lamp (broken line). The semi-frosting acts as a reflector, which reflects upwards part of the light radiated downwards.

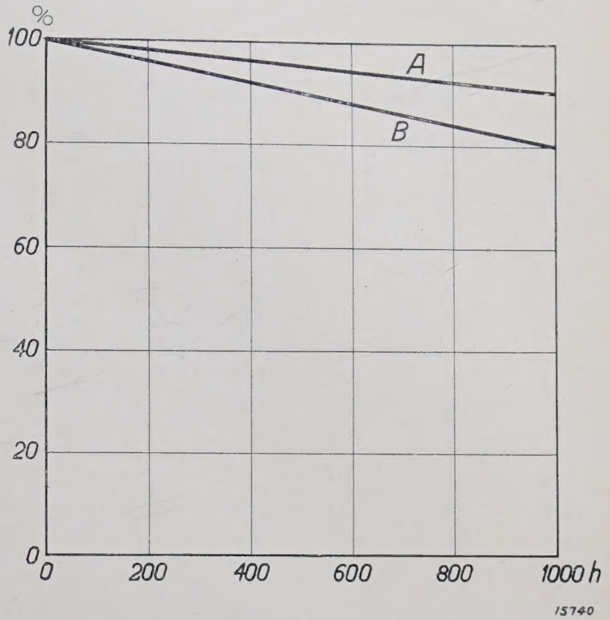

Fig. 8. Diminution in the efficiency of a lamp with use.
A Single-coil lamp.
B Coiled-coil lamp.

In conclusion, it may be stated that the substitution of the coiled-coil for the single-coil has resulted in a saving in power of 7 to 10 watts, the initial luminous flux of the two types being the same. Considering the whole life of the lamp, a better illumination is also obtained, for, as shown in *fig. 8*, the decline in luminous efficiency with the age of the lamp is much less with the coiled-coil than with the single-coil filament.

CHARACTERISTICS OF THE EYE WITH SPECIAL REFERENCE TO ROAD LIGHTING

By P. J. BOUMA.

Summary. Following a brief discussion on the way in which objects are seen on artificially-illuminated highways, the circumstances in which the eye is likely to fail are studied. The efficient or imperfect functioning of the eye is determined mainly by the visual acuity, the contrast sensibility, the richness of contrast and the speed of vision. The interconnection of these phenomena is discussed in reference to the following characteristics of the eye: Accommodation, diameter of pupil, chromatic and spherical aberration, astigmatism, adaptation, glare and the Purkinje phenomenon.

When the question is asked: "What constitutes really good road lighting?" the extreme complexity of the problem entailed must be adequately realised. The solution of this problem can only be arrived at by the closest collaboration between the most divergent branches of science, while considerable practical experience is also imperative. It must be borne in mind that particularly in the interests of safety on the road the conditions of lighting must be such as to afford distinct vision. Apart from a host of technical and physical factors (such as the distribution of brightness, the physical composition of light, etc.), the conditions of vision are in large measure determined by the intrinsic characteristics of the human eye itself. A detailed study of these characteristics is hence indispensable in dealing with the problem of road lighting.

The eye is one of the most remarkable organs with which Nature has endowed us; remarkable for the many divergent functions which it can fulfil, for its enormous sensibility, and finally for the wide variety of conditions under which it operates as an efficient instrument.

On the other hand, in studying the properties of the eye with reference to road lighting, we shall frequently have to consider the defects and shortcomings of this remarkable organ, since to ensure safety of the highway it is essential to know when and under what conditions the eye is likely to fail in the discharge of its duty; for this failure is the cause of many accidents which could be avoided by better lighting.

To determine which characteristics of the eye are the most important in this connection, we must first establish exactly in what way objects are seen on highroads. We perceive an object in the street because it stands out from its background, i.e. because usually its brightness differs from that of the background. (Differences in colour may also play a part, although usually only a subsidiary one, in creating this contrast.) When we have perceived the object, we must also recognise it, i.e. distinguish its from and distance. It is also of the greatest importance that this recognition take place rapidly; sometimes an object only remains a short time in a position suitable for its recognition and frequently rapid recognition is necessary in order to take timely measures to prevent an accident.

From the above it follows that the principal causes for the failure of the eye to perform its due functions may be classified in three groups:

1) The impossibility of perceiving very weak contrasts: when the contrast is very small, the object will not be perceived at all.
2) The image of the object impressed on the retina is not sufficiently well defined: the object is not recognised.
3) The eye functions too sluggishly: the object is not perceived or recognised quickly enough.

The second cause is the simplest to discuss, and in this respect there is a considerable similarity between the eye and a photographic camera. Exactly as the camera lens throws an image of an

object on the photographic plate, so does the lens of the eye impress an image of the object viewed on the retina. The focal length of the lens of the eye can be altered by the contraction of certain muscles. This alteration is termed accommodation, and it enables us to form sharply-defined images of objects at very different distances from the eye on the retina successively. Accommodation can be obtained consciously and voluntarily; usually it is, however, created involuntarily by force of habit. Furthermore, the eye is also equipped with a variable diaphragm by means of which the effective diameter of the lens — and hence the quantity of light falling on the eye as well as the quality of the image — can be varied. This adjustment of the diameter of the pupil takes place quite involuntarily and is a reflex action caused by external influences.

The lens of the eye is subject to the same optical defects in the production of images as ordinary lenses. Those defects which only cause a distortion of the image are usually not disturbing in the case of the eye, for in spite of this distortion the brain is capable of visualising the correct shape and form of the actual object. The clearest proof of this is the fact that the inverted image on the retina presents no difficulties, and that it is possible by the use of an optical system which turns the image through a right angle (i.e. turns it on to its side) to see "normally" again after a time. On the other hand, those defects of the eye may prove very troublesome which cause rays emanating from a point of the object not to meet at the same point on the retina. The principal defects of this type, which all adversely affect the "definition" or "sharpness" of the image on the retina and hence also the visual acuity are:

1) Lack of accomodation, which may be due to two causes:

   a. Because the object is situated at a distance to which the eye cannot be sharply focussed, the normal eye can be sharply focussed to distances between about 12 to 15 cm and infinity; with short-sighted and long-sighted eyes this range is smaller.

   b. Because the object emits light of different wavelengths and the focal length of the eye lens depends on the wavelength (see *fig. 1*). Fig. 1 shows for example that an eye which is sharply focussed for a wavelength of $\lambda = 5550$ Å possesses a myopia (short-sightedness) of 3.5 diopter at 4000 Å and a hypermetropia (long-sightedness) of 1.8 diopter at 7000 Å [1]). This phenomenon — chromatic aberration — can only be avoided by using monochromatic light.

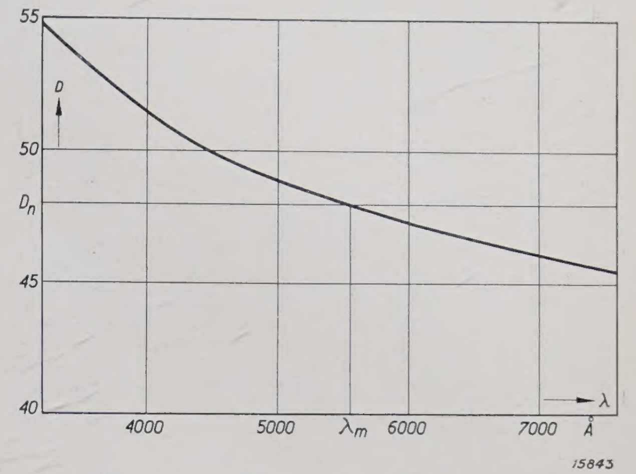

Fig. 1. Refractive power in diopter D of the normal or emmetropic eye at rest a sa function of the wavelenght λ. At the wavelenght $\lambda = 5550$ (maximum of the visibility curve of the eye), the refractive power of the normal eye is approx. $D_n = 48$. As may be seen from the graph the eye is myopic with reference to blue light and hypermetropic with reference to red light.

2) The phenomenon that monochromatic rays emanating from a point are not focussed at a point. This defect — spherical aberration — which is shared by every normal eye, can be avoided by a stronger curtaining of the eye lens (either by involuntary contraction of the pupil of the eye or by placing an artificial pupil in front of the eye).

3) Astigmatism: The rays emanating from a point and travelling in a horizontal plane have another focus than those rays lying in a vertical plane. This asymmetry of the eye is of common occurrence, frequently in conjunction with myopia and hypermetropia; it is dependent on the wavelength (*fig. 2*).

These three defects all affect the visual acuity and hence render the recognition of objects at a great distance more difficult.

To investigate in further detail the first-mentioned cause of defective vision (the impossibility of perceiving small differences in brightness), we must regard the eye as a measuring instrument capable of measuring brightness values. In such an instrument the first point to consider is the magnitude of the measuring range, in other words the range of brightness over which the eye is still a serviceable instrument. This range is much greater with the eye than with most physical

1) The number of diopter *(D)* of a lens is the reciprocal of the focal length in metres. For the normal eye in a position of rest D_n is approximately 48.

measuring instruments, for the eye can function well at brightness levels differing by a factor of

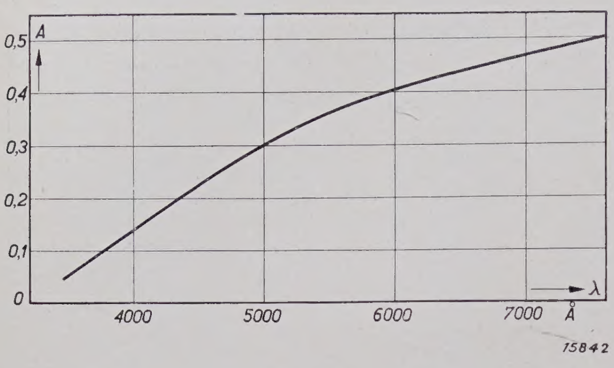

Fig. 2. Astigmatism A of a myopic eye in diopter (i.e. $1/f_1 - 1/f_2$, where f_1 and f_2 are the focal lengths for light beams in the horizontal and vertical planes respectively) for the myopic eye of the author at different wavelengths λ.

10^8 or 10^{10}. In a technical instrument, for instance an ammeter, the measuring range can be increased by attaching shunts, and for a specific range of the magnitude under measurement the sensitivity of the instrument is then adapted to the values to be measured. The sensibility of the eye can be similarly altered by a process here termed adaptation, viz, by making two different adjustments, which both take place involuntarily when the eye is exposed for a time to a certain brightness level:

1) By altering the diameter of the pupil, the latter becoming smaller the greater the brightness [2]) of the field of view *(fig. 3)*; this alteration does not take place instantaneously, and actually occupies a time interval of the order of 1 second.
2) By changes in the properties of the retina with the illumination intensity; if for instance the eye is first exposed to a high and then to a low brightness, the retinal sensitivity will increase for these low intensities after a time. The change is very slow; for while the eye adapts itself to a high intensity in a few minutes, adaptation to very low brightness levels may sometimes take several hours.

It requires no detailed explanation to show that the speed and degree of adaptation has an important bearing on road-lighting problems, particularly where considerable fluctuations in the illumination falling on the eye may take place, for the capacity of the eye depends in a large measure on its state of adaptation.

In addition to the measuring range of a measuring instrument we are also interested in its sensibility, which is determined by the smallest still just detectable difference in the magnitude under measurement. The tendency is frequently therefore to make the sensibility throughout the whole measuring range roughly the same, i.e. to design the instrument on such lines that the percentage changes just detectable are the same throughout the range.

In the case of the eye this requirement is fulfilled over a wide range of brightness values, and including practically all brightness values covered by daylight; at very low and very high intensities the sensibility of the eye diminishes. If a brightness of $H + \Delta H$ can still just be distinguished from a brightness H, the ratio $H/\Delta H$ is termed the contrast sensibility (see *fig. 4)*. It is nearly constant over a wide range of brightness values (Weber-Fechner law). In road lighting, on the other hand, we are always concerned

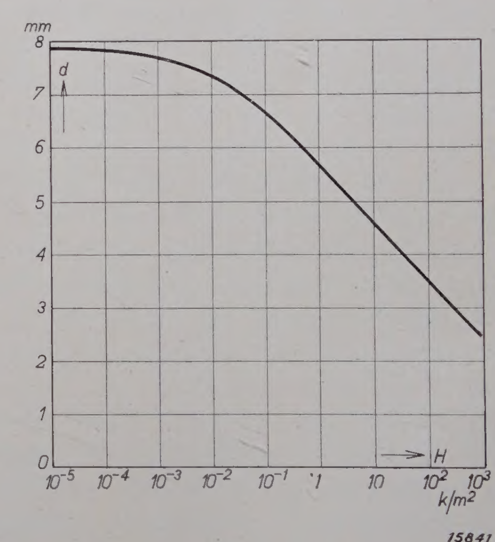

Fig. 3. Diameter of pupil d as a function of the adaptation brightness H; with increasing brightness the pupil contracts from 8 to $2^1/_2$ mm (Reeves). The unit of brightness is the candle per sq.m. = 10^{-4} stilb = 0.092 foot candle.

with a range in which a reduction in brightness results in a diminution in the contrast sensibility. As the perception of an object depends on the contrast between it and its background, it is evident that the contrast sensibility is here an important factor. Fig. 4 shows for instance that with a

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2) Brightness values are always expressed in candles per sq.m. (1 candle per sq.m. is equal to 10^{-4} stilb = 0.292 foot candle). To visualise the order of magnitude of this brightness unit, it should be noted that a surface which is illuminated with 1 lux (0.093 foot candle) and by which the whole of the incident light is perfectly diffusedly reflected has a brightness of $1/\pi$ candles per sq. m. The concept of brightness cannot be discussed in detail in this article, but will be dealt with comprehensively in a subsequent article.

brightness of 0.3 candle per sq. m. (= 0.028 candle per sq. ft.) on the surface of the highway an object whose brightness differs by less than 4 per cent

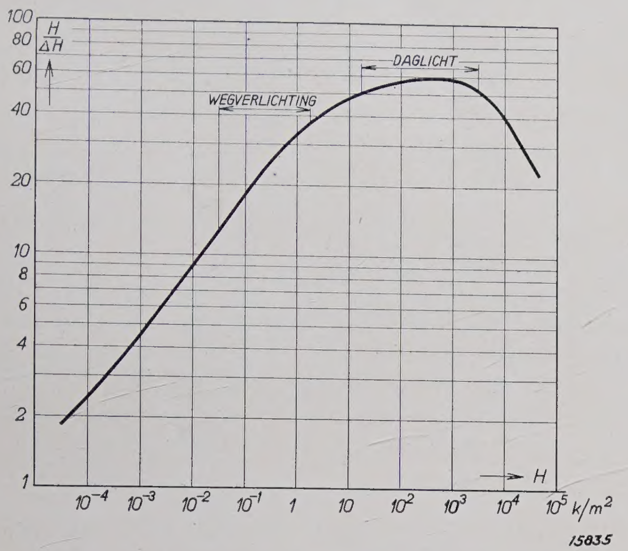

Fig. 4. The contrast sensibility $H/\Delta H$ for white light as a function of the brightness H is practically constant in daylight (Weber-Fechner), but varies strongly with the brightness in the case of road lighting (König).

from that of the highway, i.e. $H/\Delta H > 25$, cannot be perceived even under the most favourable conditions.

A third cause for the defective functioning of the eye may lie in its sluggish operation. This rate of operation — the speed of vision — depends inter alia on the following factors:

1) The time of exposure or illumination which is necessary to produce a satisfactory image on the retina.

2) The time required for the construction of an image on the retina. (Construction of the image may in certain circumstances persist even after exposure.)

3) The time elapsing before the image is impressed on the brain.

The first time-element depends on the sensibility of the eye, the second on a chemical reaction time and the third on a psychical reaction time. The complexity of this mechanism is thus obvious. In general it may be assumed that the speed of vision increases with brightness (see *fig. 5)*.

If the road-lighting system is so devised that in normal circumstances the visual acuity, the contrast sensibility and the speed of vision suffice for distinct vision, these magnitudes may still drop below their critical values as a result of one part of the retina (not necessarily that part on which the image is impressed) being exposed to a much greater brightness than the rest of the retina. Glare is then experienced. Both during the presence in the field of vision of a light source causing glare and after the disappearance of such source, the visual acuity, the contrast sensibility

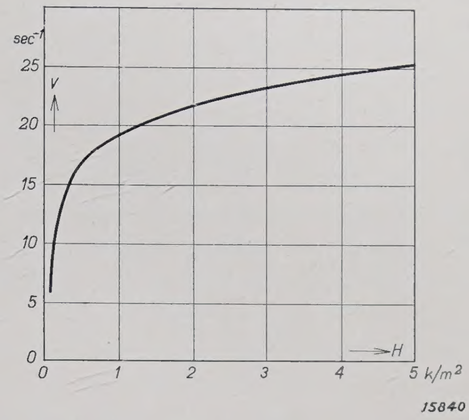

Fig. 5. Speed of vision V (reciprocal of the time of illumination of a specific object which is required just to perceive it) as a function of the brightness H (Weigel).

and the speed of vision are reduced. Frequently glare may be regarded as the production of an unsatisfactory state of adaption.

Finally, a factor must be referred to which — in particular with low brightness values — has a marked effect on the measurement and interpretation of brightnesses, viz, the fact that individual parts of the retina have intirely different structures. The retina contains two types of elements sensitive to light stimuli, the cones and the rods. In the centre of the retina is a nearly circular yellow spot (macula lutea) with a diameter of approximately 2 mm. Outside this yellow spot the retina is composed almost exclusively of rods. In the yellow spot the number of rods per sq. mm. diminishes progressively from the edges to the centre, while the number of cones rapidly increases. At the centre of the yellow spot (fovea centralis, diameter about 0.25 mm) no rods occur at all, whilst the cones are packed closely together. The cones and rods behave very differently in the following respects:

1) The rods give us an impression where all objects have the same colour (a bluish grey), while the cones are able to perceive colour differences.

2) At very low brightness levels only the rods register a sensation, and at high intensities practically only the cones; in the intervening transition range both types of elements func-

tion. The brightness values obtained with road-lighting systems are generally situated in the upper part of this transition range.

3) The sensibility of the rods to light-rays depends on the wavelength in an altogether different way to that of the cones (see *fig. 6*).

These differences result in a group of phenomena which are included under the name of the Purkinje phenomenon and may play an important part on comparing lights of different colours.

In particular, these phenomena affect the brightness ratios of the various parts of the field of vision, i.e. the richness of contrast. This richness of contrast is also an important magnitude with regard to the perception of objects. Also when the contrast is already considerably greater than the value required in view of the contrast sensibility, an object is perceived with still greater certainty and more quickly the more pronounced the contrasts are, i.e. the greather the richness of contrast.

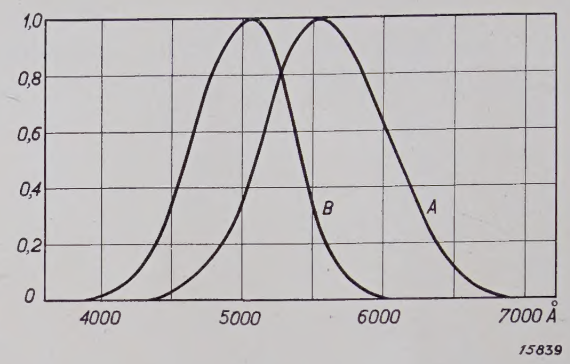

Fig. 6. Visibility curves of the eye (relative reciprocal values of the energy required to obtain a uniform "impression of brightness" as a function of the wavelength λ):
A) For the cones (valid for brightnesses exceeding 3 candles per sq.m. = 0.28 candle per sq. ft.).
B) For the rods (valid for brightnesses in the neighbourhood of the absolute threshold value of the eye).

In a series of further articles we shall enter in greater detail into the concepts mentioned here.

THE PHILIPS-MILLER SYSTEM OF SOUND RECORDING

By R. VERMEULEN.

Contents. On the ordinary disc sound is recorded and reproduced *mechanically*; in the photographic method of sound recording, both recording and reproduction are carried out by *optical* means. Mechanical reproduction on the one hand and optical recording on the other hand possess certain inherent disadvantages. The Philips-Miller system of sound-recording, whose principles are discussed in this article, avoids these disadvantages, in that the sound-track is recorded on the film by *mechanical* means and is then *optically* reproduced.

The art of recording music and speech with high fidelity — it is impossible to conceive of modern life existing without it — has been employed in a host of directions. It is the medium for bringing music into the homes of all, it has proved useful in the teaching of languages, it is employed for producing ethnographical and cultural documents and records, in ordinary office work (in the form of the dictaphone), and on a more magnificient scale for producing sound-films and for broadcasting purposes. Particulary the latter two fields of application have made very specific demands, not always easy to fulfil, on the methods employed for recording sound.

In the oldest form of sound-recording apparatus, the *Edison* phonograph, the recorded sound-track was inscribed on a wax cylinder. Where no copies of the sound-track are required and the quality of the sound does not have to satisfy special requirements, as for instance in the dictaphone, this earliest method of recording is still employed to the present day. In later methods a magnetisable steel wire, a wax disc, or a strip of film or paper chart were, or are still being, used for recording a sound-track.

For reproducing music in the home, the classical method of sound-recording continues to be employed, viz, the gramophone disc. It is evident therefore that in making the first sound-films the gramophone disc was also selected to carry the recorded sound. Certain difficulties were, however, soon found to be inherent in sound-tracks on discs, as for instance the difficulty of synchronising the sound after "cutting" and "splicing" the film, and the frequent changing of the discs which was necessary owing to their short playing time, etc. For this and other reasons another method of recording sound was adopted in sound-film work, viz, the production of a sound-track on the film strip itself. The sound-track was inscribed by optical means, the blackening produced by a narrow beam of light on the photographic surface being made to vary in synchronism with the sound vibrations either in dimensions (variable width) or in intensity (variable density) (see figs. 5 and 6). Various inconveniences inherent in this method, such as the time lost for developing the film, a weakening of the higher notes, etc., were temporarily tolerated or complicated means were evolved for remedying them.

In the Philips Laboratory a new method for recording sound has been evolved in the last few years, which is based on a principle proposed by J. A. *Miller*. A description of this Philips-Miller system, which has now reached a high stage of perfection, is given below. In this article it is proposed to describe in the main the principle employed and to compare this new method with those in use hitherto. The technical development of the basic principle of the Philips-Miller system introduced a number of special problems, the solution of which will be discussed in a series of articles in this Review.

1) "Splicing" is the operation of joining together a number of pieces of film in the required order to produce the final sound film or news reel.

Basic Principle of the Philips-Miller Method

In the Philips-Miller method as in the photographic sound-film processes a sound-track is recorded on a strip of film. However, this is not done by optical means as hitherto but by mechanical means. The film material, the "Philimil" tape, consists of a celluloid base, which in place of the usual photographic emulsion is coated with an ordinary translucent layer of gelatine about 60 μ in thickness, on which a very thin opaque surface layer about 3 μ in thickness is affixed. Perpendicular to the tape, a cutter or stylus shaped like an obtuse wedge as shown in *fig. 1* moves in synchronism with the sound vibrations to be recorded. This cutter removes a shaving from the gelatine layer which is displaced below it at a uniform speed.

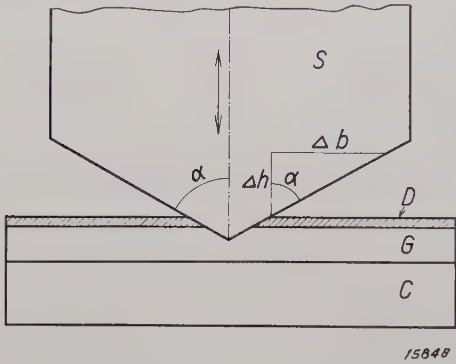

Fig. 1. Section through the wedge-shaped cutter S and the "Philimil" tape. The latter consists of a celluloid base C, a transparent layer of gelatine G and a very thin opaque coating D. The cutter shaves a groove from the tape which is moved under the cutter. The coating D thus being removed along this groove, a transparent track on an opaque background is obtained. By making the cutter in the form of an obtuse wedge, small elevations and depressions Δh of the cutter produce marked changes in width $2\Delta b$ of the inscribed track; with a semi-apical angle of the wedge α the "magnification" is $2 \tan \alpha$. In practice α is made 87 deg, hence $2 \tan \alpha$ = about 40.

If the cutter remains stationary, it cuts a groove of uniform width $2b$ in the film below it. Along this groove the thin top coating (and a part of the gelatine layer) is removed, so that a transparent trace is obtained on an opaque background. If the cutter is now brought deeper into the film by a distance Δh, the groove cut will become wider by a small amount $2\Delta b$ (cf. *fig. 2*) and if α is half the apical angle of the wedge (fig. 1) the relationship

$$2 \Delta b = \Delta h \cdot 2 \tan \alpha$$

will apply. At $\alpha = 90$ deg, $\tan \alpha$ will be infinity; it is thus seen that if α is nearly 90 deg a slight displacement Δh of the cutter will produce a marked alteration $2\Delta b$ in the width of the recorded trace. With 87 deg, the angle of the wedge used in practise, the "magnification" obtained will be $2\Delta b/\Delta h = 2 \tan 87$ deg, i.e. about 40.

Now if the cutter moves up and down in synchronism with the sound vibrations to be recorded (perpendicular to the tape), a transparent track on an opaque background will be produced on the moving tape whose width will vary in synchronism with the sound vibrations *(fig. 3)*. To

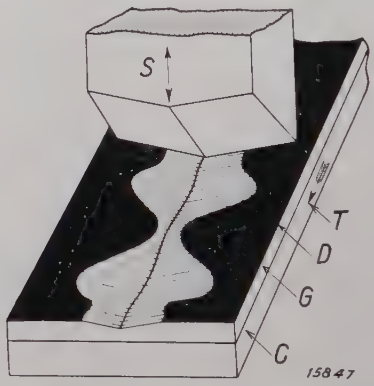

Fig. 3. The cutter S moves up and down in synchronism with the sound vibrations to be recorded (perpendicular to the plane of the tape). D, G and C represent the same as in fig. 1. A transparent sound-track on an opaque background is produced on the "Philimil" tape which moves under the cutter in the direction T.

obtain a maximum width of trace of $2b = 2$ mm, as commonly used in sound-film recording practice, the displacement of the cutter need only have a double amplitude Δh of $2000/40 = 50$ μ. The principal characteristic of the whole method is this small magnitude required for the cutter amplitude.

The recorded sound is reproduced by the usual method employed in optical sound-film technology. The film carrying the sound-track is moved between a photo-electric cell and a small, brightly

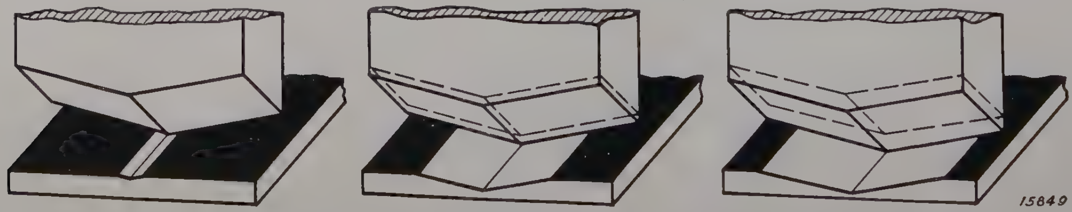

Fig. 2. The width of the track inscribed in the tape for three different positions of the cutter.

illuminated slit (transversal to the direction of motion of the film). The intensity of the light falling on the photo-electric cell thus varies with the variable width of the sound-track, and the resulting current fluctuations in the photo-electric cell are amplified and passed to a loudspeaker.

The Philips-Miller system is thus a combination of a mechanical recording method with an optical method of reproduction. This unique association offers distinct advantages over the methods hitherto in use, as will be evident from the discussion below.

Mechanical Sound Recording and Reproduction on Discs

Sound is recorded on the gramophone disc by mechanical means: an oscillating cutter (scribing stylus) cuts an undulating groove in a wax disc *(fig. 4)*. Reproduction is also performed mechanically, the gramophone needle

Fig. 4. Undulating grooves of a gramophone disc. View from above and in section.

(reproducing stylus) being made to follow the undulation of the groove. The disc is manifolded with the aid of a mould produced by electrodeposition. This process is very suitable for producing large numbers of a record and will therefore not be easily superseded by any other process. Yet it possesses certain general disadvantages in in addition to those already referred to and which are particularly undesirable for sound-film work, viz, the short playing time of a disc and the difficulty of excising part of the sound-track. As a result of mechanical playing back the disc is subject to considerable wear; even if the needle is changed each time the disc is played, the quality of reproduction is still noticeably reduced already after playing the disc 20 times. Moreover, the resistance to motion produced by the needle on the revolution of the disc depends on the intensity of modulation in the sound-groove, so that in a loud passage (particularly of pianoforte music) the disc may be retarded, with the production of the well-known undesirable booming effect [2]).

Above all the method of reproduction introduces an unavoidable falling-off in the higher notes. The wear and resistance to motion of the disc are due to the needle on travelling through the groove sustaining considerable accelerations, i.e. great forces, at all highly curved points. In fact with too great a curvature in the groove the needle may even stick or break down the walls of the groove. It follows, therefore, that the curvature of the groove must not exceed a certain value (as may be readily seen, the radius of curvature must not become smaller than the width of the groove). The groove has an undulating form expressed by the equation $A \sin \omega x$, where A is the amplitude, and ω the frequency of the recorded sound; the maximum curvature and hence also the force is then proportional to $\omega^2 A$. It would, therefore, if A were constant, assume high values at the high frequencies. On prescribing that the forces must for the high frequencies remain the same as for the low ones, provision must be made in sound-recording such that the (fully-modulated) amplitude A diminishes in proportion to $1/\omega^2$. This would, however, result in such small amplitudes at the higher frequencies, that they would become indistinguishable from the ever-present small surface inequalities of the material, with the result that the higher notes would be submerged in the ground noise (surface noise) of the disc itself. Moreover, for the lower notes the amplitudes obtained would be too great, so that the distance between the grooves would have to be made very large and the discs thus become most cumbersome (or the playing time become undesirably short). In practice, therefore, a recording method is adopted in which, at full modulation, an amplitude is recorded proportional to $1/\omega$ (instead of to $1/\omega^2$) [3]). Such a frequency characteristic is in fact also very suitable for electro-

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2) During recording the load on the driving motor naturally also varies according to the intensity of modulation. This fluctuation in load can be conveniently taken up here by a fly-wheel. The addition of a massive fly-wheel to a gramophone for the home would, however, not be a very satisfactory solution.

3) At the lowest frequencies, the amplitudes are even made independent of the frequency.

magnetic reproduction. The needle is connected with an armature or a coil which moves in a magnetic field. The voltage produced by displacement of the armature, which latter for instance may be represented by $A \sin \omega t$, is proportional to the velocity $\omega A \cos \omega t$ of this displacement, i.e. proportional to the product ωA of the frequency and the amplitude. Since according to the above method of recording the inscribed amplitude A of the groove is proportional to $1/\omega$, ωA remains constant, so that we obtain directly the required constant (frequency-independent) output voltage which is passed to the valve amplifier. However, with this frequency characteristic (A proportional to $1/\omega$ instead of to $1/\omega^2$), the amplitudes of the lower notes and the curvature of the groove for the higher notes would still become too great, so that at both ends of the frequency range the amplitudes must be reduced (see footnote [3]). This loss can be compensated at the lower frequencies by selecting a suitable characteristic for the valve amplifier, but at the higher frequencies such compensation would at the same time result in a more marked ground noise.

All these disadvantages; wear, retardation of the disc, and degeneration of the high frequencies, are as we see only due to mechanical reproduction and not to mechanical registration.

Optical Sound Recording and Reproduction from Sound-Film Tracks

Optical registration of the sound-track on a film strip represented a marked advance in sound-film technology. The playing time was now made much longer, being the same as for the picture itself. Synchronising vision and sound, and film cutting and splicing were also much simplified. Wear resulting from (optical) reproduction no longer occurred, nor a fluctuating load placed on the motor which pulls the film through the reproduction machine. Optical reproduction thus offered a very satisfactory solution of the problem. Also manifolding is very simple since as many copies as required can be obtained by photographic means.

Certain drawbacks of the optical method are, however, inherent in the method of recording the sound track. The film is exposed by an illuminated slit of varying intensity (variable-density record, *fig. 5*) or of varying length (variable-width record, *figs. 6* and *7*). The illuminated slit always has a definite width, e.g. 25 μ. With a film speed of 50 cm per sec $= 20000 \cdot 25\ \mu$ per sec, each part of the film is therefore in front of the slit for a period of 1/20000 sec. With a vibration of 5000-

Fig. 5

15855

Fig. 6

Fig. 5. Sound-film strip with variable-density sound-track. The sound-track is produced by illuminating the film through a slit situated transverse to the direction of motion of the film, the intensity of illumination (or the width of the slit) being varied by the sound vibrations.

Fig. 6. Sound-film strip with variable-width sound-track. This sound-track is produced by varying the length of the illuminated slit in synchronism with the sound vibrations, see fig. 7.

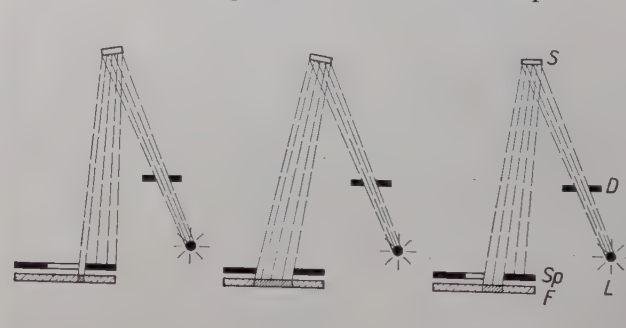

Fig. 7. Arrangement for the photographic recording of a variable-width sound-track. From the light emitted from the constant light source L a beam is passing through the diaphragm D. The mirror S mounted on a sensitive oscillograph throws the beam of light on to the slit Sp, under which the film F is moved (perpendicular to the plane of the paper). When the mirror S commences to swing under the action of the sound to be recorded, the sharply-focussed beam of light oscillates to and fro over the slit Sp and produces a blackened band of varying width on the film (see fig. 6). The path of the rays is shown for three different positions of the mirror.

cycle frequency, the brightness of the slit with a variable-density record or the length of the slit with a variable-width record varies quite considerably already in this period of time, so that the modulation recorded on the film decreases in intensity in favour of an increasing uniform blackening over the whole width (or, with the variable-width method: part of the width) of the film.

The finite width of the slit thus results in a certain degeneration in reproduction of the high notes [4]). The same effect is also produced by the unavoidable grain and halation due to dispersion and reflexion of light (cf. *fig. 8*) in the photographic material; the grains and the lack of definition at the edges of the sound-track produce a murmur on reproduction, which again affects especially the high notes.

In fact the use of photographic material is not very satisfactory. After the sound has been recorded it is necessary to wait until the film has been developed, which frequently results in much inconvenience owing to loss of time (it is usually necessary to wait until the next day). It is true developing can be accelerated but speed is only obtained at the expense of quality. The blackening produced on the film must depend in a definite way on the exposure in order to obtain undistorted reproduction [5]), and to satisfy this requirement it is essential to exercise considerable care in developing.

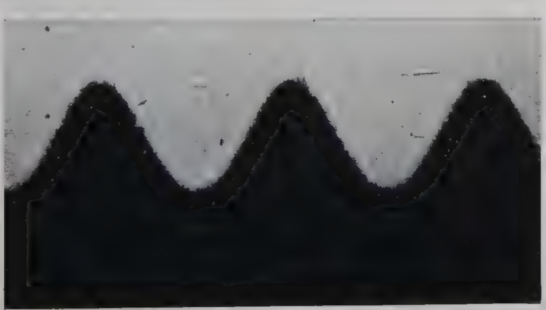

Fig. 8. Microphotograph of a variable-width record of a 1000-cycle note. Owing to the grain and dispersion of light in the emulsion the track is not wholly sharp. Magnification approx. 50 times.

We thus see that in the optical method the disadvantages (loss of time and also deterioration of the high frequencies) are due mainly to optical recording on the photographic material, and not to the method of optical reproduction.

Mechanical Sound Recording on a Tape

In the Philips-Miller method the disadvantages of mechanical reproduction as well as those of photographic recording are avoided, since reproduction is effected by optical means and registration on the film by mechanical means. Already before Miller, various other methods had been evolved to the same end, but all proved unsuccessful as the mechanical recording of sound on the film had to face insuperable obstacles. Some details of these difficulties will be discussed here.

In optical reproduction of the sound-track, the fluctuations in light, i.e. the modulation of the track width on the "Philimil" tape are converted directly into voltage fluctuations. In contrast to the method of reproduction with discs where, in agreement with the insertion of the electromagnetic system, the recorded amplitude was made to diminish with increasing frequency, in the optical method of reproduction the recorded amplitude is made independent of the frequency, in order to obtain an output voltage independent of frequency. *Fig. 9* shows in a striking manner the difference in sound-recording with both these types of amplitude-frequency relationship. One and the same sound vibration has been recorded on the

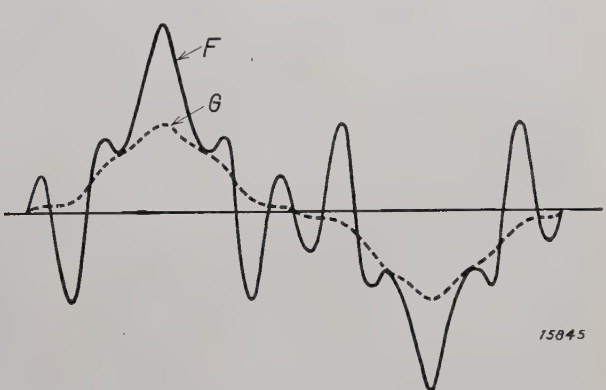

Fig. 9. Records of exactly the same sound vibrations using two different amplitude-frequency relationships. For optical reproduction (film) the amplitude must be independent of the frequency with a given intensity of sound (continuous sound curve *F*). For mechanical reproduction (disc), the amplitude must be inversely proportional to the frequency (dotted sound curve *G*). It is seen that in the first case (continuous sound curve) the higher frequencies are much more pronounced in the sound-track.

4) This effect of course is also obtained in the (optical) method of reproduction, but if it only occurs during reproduction it is not yet so troublesome as when it occurs twice, viz, during both recording and reproduction.

5) This condition is also due to the finite width of the slit. With an infinitely narrow slit, the law of blackening can have any arbitrary from in the variable-width method where the length of the illuminated slit is varied, but not so with a finite slit, owing to the half shadows produced at the edges (in variable-density recording where the intensity of blackening is varied, still more severe requirements must be met as regards accurate maintenance of the prescribed relationship between blackening and the incident amount of light).

basis of each frequency relationship. It is seen that on the film (amplitude for optical reproduction being independent of the frequency) the high frequencies are much more distinctly recorded than on the disc (where the amplitude diminishes with the frequency), and are hence also situated higher above the interference level. The normal width of the sound-track on the sound-film is 2 mm. The sound-recording machine must therefore record an amplitude of 1 mm.

How must a system be designed for mechanically recording sound? Let the stylus or cutter be attached to a spring-controlled armature, which for instance may be driven electromagnetically by the amplified microphone currents. The mechanism can be visualised as a mechanical oscillator of mass m (armature with cutter), a directional force c (spring control) and a certain damping constant r. If the system is set in motion by a force $k \sin \omega t$, it will oscillate with an amplitude:

$$A = \frac{k}{\sqrt{(c - m\,\omega^2)^2 + (r\,\omega)^2}} \quad . \quad . \quad (1)$$

This equation can be reduced to the form:

$$\frac{A}{k/c} = \frac{1}{\sqrt{[1 - (\omega/\omega_0)^2]^2 + \delta^2\,(\omega/\omega_0)^2}} \quad \ldots \quad (1a)$$

where $\omega_0 = \sqrt{c/m}$ is 2π times the natural frequency of the undamped system and $\delta = r/\sqrt{mc}$ is the only parameter contained in this expression. *Fig. 10* shows $A/(k/c)$ plotted against ω/ω_0 for various values δ of the parameter. If the damping is not too high ($\delta < 1$), resonance is obtained in the neighbourhood of $\omega/\omega_0 = 1$, i.e. when the driving frequency ω is close to the natural frequency ω_0. The curves show that it is essential to remain below the resonance frequency if an amplitude sufficiently independent of the frequency is to be realised, or alternatively, since the frequency range of sound registration is fixed (up to approx. 8000 cycles) the driving system (sound recorder) must be so dimensioned that its natural frequency $\omega_0 = \sqrt{c/m}$ lies within the range of the highest frequencies to be recorded. For this purpose it is evident that the controlling force c must be made large and the mass m small. The diminution possible in the mass of the armature is, however, limited by the dimensions which it must have in order to obtain the requisite driving force to overcome the resistance of the tape and inertia of the cutter. We are therefore constrained to make the directional force (of the spring) c of the system very large, but this in its turn results in the amplitude A, with which the system responds to one and the same force k, becoming undesirably small; this follows from equation (1). This drawback cannot be remedied, either, by increasing k arbitrarily, since this will lead to an increase in the stress on the material and soon exceed the permissible limiting load.

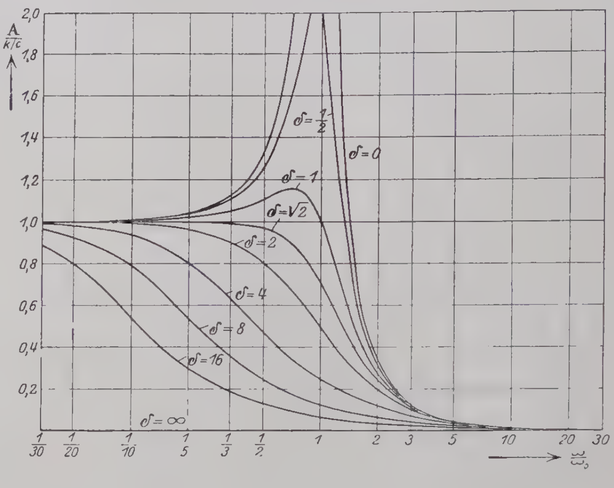

Fig. 10. Resonance curves of an oscillating system (spring controlling force c, mass m, damping r) set in motion by a force $k \sin \omega t$. The frequency ratio ω/ω_0 ($\omega_0 = 2\pi$ times natural frequency) is plotted along the abscissa (which for convenience' sake is divided logarithmically), and the ratio of the amplitudes $A/(k/c)$ (A = amplitude with which the system responds to excitation) along the ordinate. The resonance curve if plotted in these dimensionless variables is completely determined by the similarly dimensionless parameter $\lambda = r/\sqrt{mc}$. In working out the dimensions of the sound recorder the form of the resonance curve is the primary factor; δ ought to be made equal to about unity. In addition A/k should be as large as possible. (Reproduced from B. D. H. Tellegen, Arch. Elektrotechn. **22**, 62, 129.)

The conclusion must therefore be drawn that a high natural frequency and a considerable amplitude independent of the frequency cannot be realised simultaneously [6]). Miller provides a way out of the difficulty: By giving the cutter the shape of an obtuse wedge (fig. 1) the sound-track is recorded with a large amplitude (= half-width of track = 1 mm at complete modulation), while the amplitude of the mechanical oscillating system serving as sound recorder need only be comparatively small, viz, a maximum of 25 μ. These values can just be attained by most careful construction. In a following article the whole problem involved here will be discussed in greater detail. *Fig. 11* gives the frequency characteristic of the sound recorder which has been attained at present.

[6]) In the mechanical recording of sound on discs, conditions are much simpler in this respect as only at the lower frequencies is a pronounced amplitude required, but with the high frequencies a lower amplitude is needed; this kind of frequency characteristic is readily to be obtained from the ordinary form of resonance curves, see fig. 10.

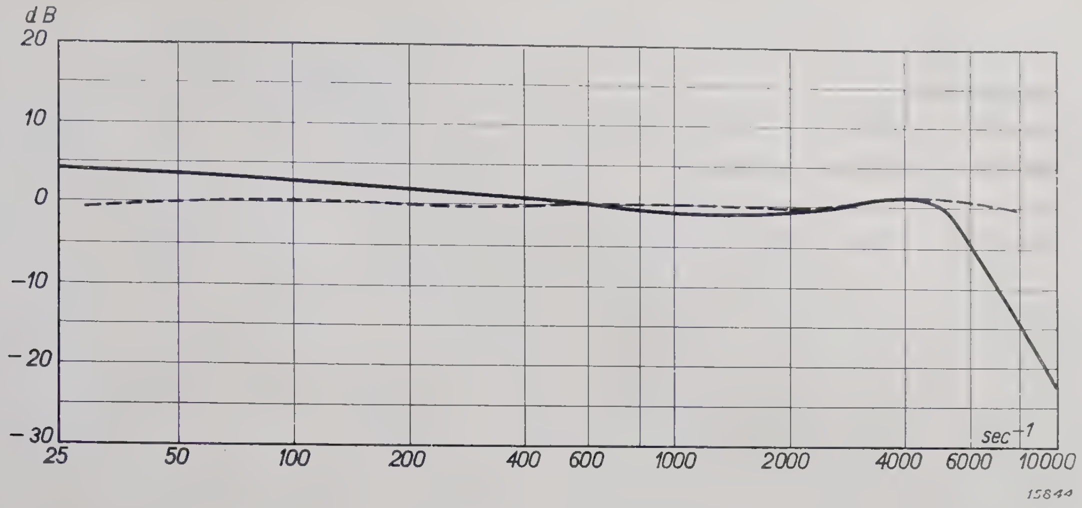

Fig. 11. Characteristic of the sound recorder (continuous curve) as at present constructed. The sound frequencies in cycles are plotted logarithmically along the abscissa and the amplitude differences in decibels along the ordinate. (A difference of m decibels between two amplitudes A_1 and A_2 ($A_1 > A_2$) signifies that the squares of the amplitudes A_1^2 and A_2^2 are in a ratio of $10^{0.1m}:1$). It is seen that the amplitude between 20 and 6000 cycles is practically independent of the frequency. The dotted line gives the characteristic of the whole recording and reproducing apparatus; by suitably designing the amplifier the characteristic is still further improved with respect to the continuous line; the differences in the range between 20 and 8000 cycles do not now exceed 2 decibels, which is hardly to be heard. Reproduction is thus free from (linear) distortion.

The high magnification with the wedge-shaped cutter called for the solution of a number of practical problems. The slightest change in the distance between the cutter and the tape, as a result for instance of a slight eccentricity of the roller carrying the tape or the presence of a particle of dust between the roller and tape, or a slight variation in the thickness of the tape, is able to cause immediately an audible distortion of the sound-track. The recording apparatus must therefore be constructed with the greatest precision, while in the manufacture of the tape every care must be taken to obtain maximum uniformity and purity of the material. This latter precaution is also necessary in order to prevent the very heavily-stressed cutter becoming damaged by particles of dust or traces of impurities in the gelatine layer.

It is also most essential to have an absolutely uniform motion of the tape. The resistance applied by the tape to the cutter, however, varies with the width of track from 0 to 2 kg, this rendering the uniform motion very difficult to be obtained. The fluctuation in load cannot be taken up by the perforation taken over from the picture film and by the driving sprocket wheel, without producing undesirable vibrations in the tape motion. A new driving method has brought the remedy here.

The recorded tape can be copied photographically in the same way as an ordinary variable-density or variable-width sound-film, but as the sound-track possesses a modulation not only in its width but also in its density, it acts on a beam of light passing through it as if it were a prism. The fluctuations in the light resulting herefrom do not cause interference, and in any case can be rendered innocuous by simple means.

Characteristics and Applications of the Philips-Miller System

The sound-track on the "Philimil" tape has the same desirable characteristics as the ordinary film: A longer playing time (30 tot 60 minutes), the possibility of cutting and splicing, and the production of copies photographically. In addition all disadvantages of the photographic material have been avoided. All operations with the film strip can now be carried out in daylight. The sound-track is more sharply recorded since no granulation and dispersion of light in the photographic emulsion occur here, see *fig. 12*. Moreover, owing to the almost complete absence of granulation in the material the ground noise has been considerably reduced. High frequencies are recorded with more fidelity; the cutter can be made so sharp that it does not alter the frequency characteristics, as was the case in the optical method of recording by the width of the light-slit.

The most important and most striking advantage offered by this method is that the sound-track

can be reproduced immediately the recording process has been completed (e.g. after 1/5 of a second). This property is of the greatest impor-

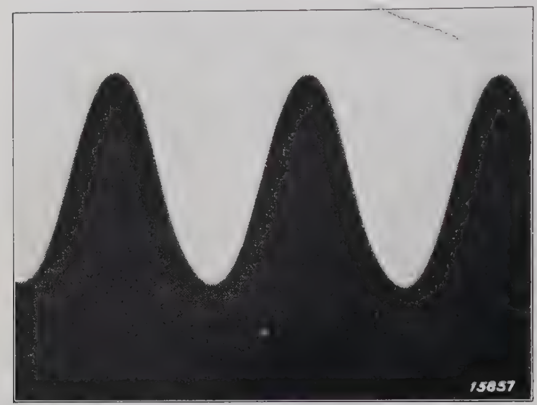

Fig. 12. Microphotograph of the sound-track of a 1000-cycle note on the "Philimil" tape, with the same magnification as in fig. 8. The coating is devoid of all grains and the edges of the sound-track are sharply defined. The ground noise is therefore much reduced.

tance and value when recording sound-films. The producer has now no longer to wait for the development of the light-sensitive film in order to decide whether the sound record conforms with his requirements. After each scene has been recorded he can listen in to the playback of the sound-track immediately and decide on the spot of the sound-track for documentary and other repeated.

For broadcasting purposes also, the immediate reproducibility of the sound-track is of the greatest utility. The exchange of programmes between stations, the postponement of the transmission of current items of news (races, speeches, etc.) to a more suitable time of the day, the production of radio plays, all these are much facilitated by the Philips-Miller system, while the tonal quality exceeds that obtainable with the wax disc. The high fidelity of reproduction also offers a method of copying sound-records which in certain circumstances may be very convenient, viz, by making a new record of the reproduced sound track on a second "Philimil" tape. This "mechanical" copying can be carried out at the same time as reproduction, so that a direct duplicate can be obtained of the sound-track for documentary and other purposes.

THE V.R. 18 TRANSMITTING AND RECEIVING EQUIPMENT

By C. ROMEYN.

Introduction

With the progressing development of commercial flying, the need for some means of intercommunication between an aircraft in flight and the airport very soon became apparent, and the first passenger and commercial airplanes, although still very small, were already equipped with wireless apparatus. With the steady and radical improvements in technical methods and apparatus during the last ten years both flying and wireless technology have made rapid strides. The importance of wireless intercommunication during flight has progressively increased and at the present day it is impossible to conceive of a passenger or commercial aircraft being without wireless apparatus. Reports of weather conditions along the aircraft route, landing instructions, direction-finding signals, etc., have become indispensable to the pilot.

It is the task of the wireless industry to provide suitable apparatus capable of meeting the special requirements for use in modern aircraft. That an aircraft radio equipment in many respects must differ fundamentally from a permanent and stationary ground equipment is obvious. In the present article the V. R. 18 aircraft transmitting-receiving equipment designed by Philips is described. This equipment has been specially evolved to meet the various requirements for use aboard aircraft, yet in its design attention has, moreover, been given to certain specialised needs

considering the application of this equipment for the Douglas air liners operating on the Netherlands East Indies route of the K.L.M. air services.

General Characteristics of a Wireless Equipment for Aircraft Use

The V.R. 18 equipment (see *fig. 1*) consists in the main of the transmitter, receiver, aerial and requisite sources of power, as well as a series of auxiliary components such as the control box, the aerial lead-through, etc. In both electrical and mechanical characteristics, all components have to be designed to meet special requirements. Thus all parts must be as light as possible and take up the minimum of space without constituting an obstruction. Furthermore, the equipment must be installed in such a way that it is not exposed to serious vibration or hard jolts. To permit the interior to be tested readily and quickly, easy dismantling of both the transmitter and the receiver is moreover desirable.

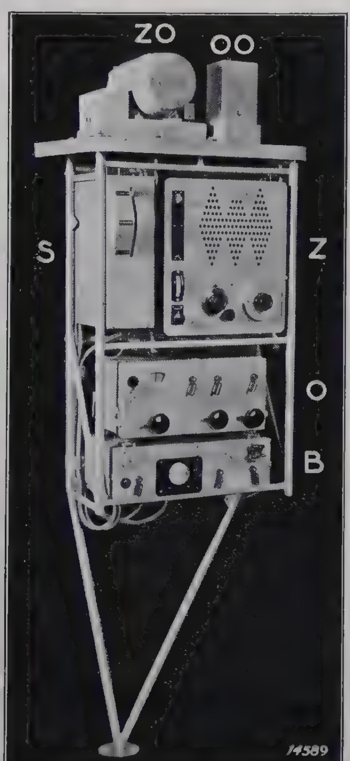

Fig. 1. Complete wireless equipment V.R. 18 for aircraft. (In the Douglas machines the various components are mounted in different places.) Z = Transmitter. O = Receiver. B = Control box. ZO = Converter furnishing anode voltage of transmitter. OO = Converter furnishing anode voltage of receiver. S = Switch for changing over from trailing aerial to fixed aerial.

Intercommunication between aircraft and airport is nowadays performed almost exclusively by telegraphic means. In this connection it is interesting to review briefly the historical development of the methods employed. During the early years of flying intercommunication with aircraft was carried out solely by means of the telephone. This instrument alone could be used at that time, since the pilot who had to operate the wireless apparatus already had both hands fully occupied in controlling the flight of the machine and it was thus impossible for him to work a Morse key. The disadvantages of using telephony became, however, steadily more apparent. In the first place, to cover the same range a telephone transmitter has to have a greater power than a telegraph transmitter; yet the most serious drawback of telephony is that it requires a wider frequency band, since, owing to modulation, an additional side band is transmitted at both sides of the carrier-wave frequency. In view of the increasing number of transmitting stations, which were concentrated in a comparatively small geographical area, the few frequency bands available were soon taken up. The only practical means for avoiding intensive mutual interference of stations was to adopt the telegraphic method of intercommunication. This made it necessary to provide a wireless operator for each aircraft in addition to the pilot. This addition to the crew would, however, have become necessary for other reasons, even without changing over from the telephone to the Morse key. The greater demands made on the pilot by the more complex problems associated with navigation (flying at night and through fog) were already making the care of the telephone an onerous additional responsibility, while on the other hand wireless intercommunication for the self-same reason, viz, the much-increased number of reports required for safe navigation, itself demanded closer attention. Moreover, it had become practicable to carry a special operator, as larger aircraft were being built in which more room was provided in the pilot's cabin.

Intercommunication between aircraft and airports is thus at the present time almost exclusively based on telegraphy. By international agreement the wave-lengths of 600, 944, 918 and 932 m have been allocated for wireless aircraft transmitters, of which the 600-m wave-length is only allowed for transoceanic flights.

The Transmitter

The transmitter of the V.R. 18 equipment is constructed for continuous-wave and tonic-train telegraphy. In the former a high-frequency oscill-

ation is radiated at intervals corresponding to the Morse signals. These oscillations are generated by a control stage S (see *fig. 2*) containing an oscillating valve (called the control valve) and a tuning-circuit. The oscillations generated are amplified by an amplifying stage V comprising two valves connected in parallel. In the anode circuit of this stage the amplified energy is fed to the transmitting aerial A. This method of wiring ensures a very constant frequency, as aerial reaction on the oscillator (control stage) is very small. For frequency adjustment the tuning-curcuit of the control stage is provided with a variable condenser, which by a snap action can be fixed in four standard positions. These four settings corespond to the above-mentioned standard international wave-lengths, but can be altered to conform to any subsequent alteration in the agreed wave-lengths.

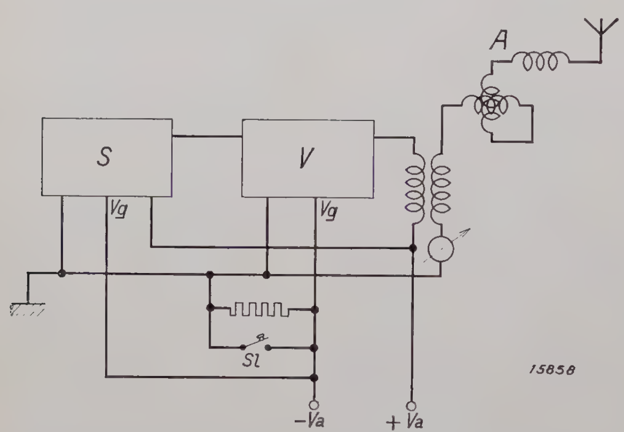

Fig. 2. Simplified circuit diagram of the transmitter V.Z. 18. S is the control stage, which generates the desired frequency, V the amplifying stage containing two valves in parallel, A the aerial circuit with aerial reaction, tuning variometer and ammeter. The voltage-drop at the resistance in parallel with the Morse key Sl is applied as negative grid bias V_g to all valves and inhibits transmission. By means of the Morse key this resistance is shorted and, as a result, the transmitter enabled to transmit in synchronism with the Morse signals.

A high negative bias V is applied to the grids of the control and amplifying valves, which inhibits the oscillation. During transmission this negative bias is removed in synchronism with the Morse signals (see fig. 2).

By means of a rotary interrupter, which is in series with the Morse key, the radiated high-frequency oscillation can, moreover, be interrupted 1000 times per second. This method of transmission, tonic-train telegraphy, is used for making the connection with some station. Owing to the greater width of the frequency band as a result of modulation with the 1000-cycle frequency, tuning is rendered more simple. But as soon as the connection has been set up, the wireless operator changes over to continuous-wave telegraphy, since the latter causes less interference owing to the absence of side bands.

The Douglas air liners on the East Indies route of the K.L.M. have to cross regions in Asia where airports are few and far between. In order to keep in communication with at least one airpost a powerful transmitter is required, and for this reason the power output of the V.R. 18 equipment in the aerial circuit has been rated at 75 watts. The range when using a trailing aerial (see below) is then at least 600 km for continuous-wave telegraphy and 300 km for tonic-train telegraphy. In certain circumstances the range may be considerably greater and on several occasions this equipment has been able to transmit over distances exceeding 6000 km. During flights in the European zone, where a large number of well-equipped airports are situated close to each other, a fairly small transmitting power is, on the other hand, sufficient for efficient intercommunication, provided atmospheric disturbances are not too serious. In fact, a transmitter with an excessive power output is undesirable for this zone, since it may interfere with the wireless signals being transmitted simultaneously from an airport to other aircraft in flight. The transmitting power of the equipment can therefore be regulated, the aerial power being reducible to either a half or a quarter by increasing the negative bias of the amplifying valves.

The interior of the transmitter, with the chassis pulled out, is shown in *fig. 3*.

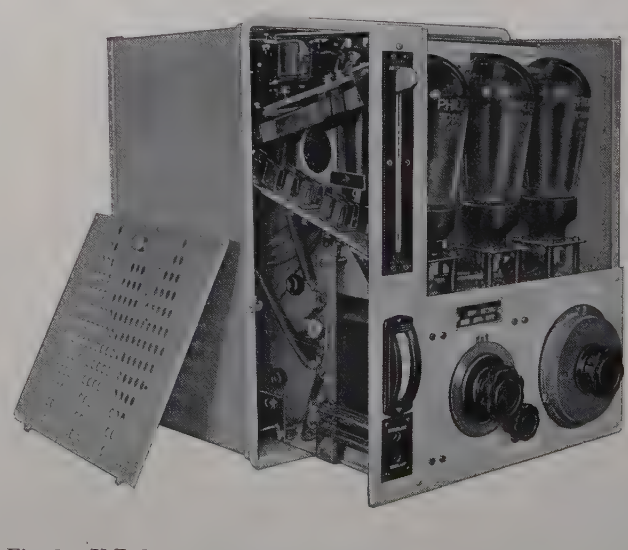

Fig. 3. V.Z. 18 transmitter with chassis drawn out and front wall removed. The housing and chassis are made of duralumin.

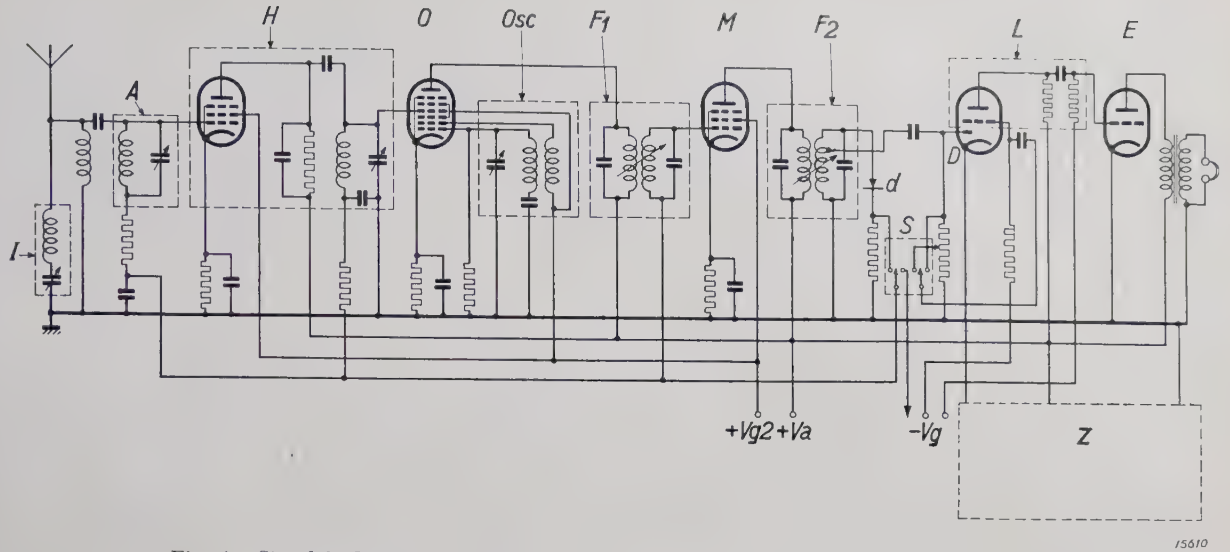

Fig. 4. Simplified circuit diagram of receiver V.O. 18. The circuit shown is that of a five-valve superheterodyne receiver, where *A* is the first tuning circuit, *H* the high-frequency amplifying stage, *O* the modulating and oscillating valve, *Osc* the oscillating circuit, which is tuned to an oscillation with a frequency differing by an almost constant amount (differential or intermediate frequency) from the tuning frequency of *A* and *H*. The three variable condensers of these three stages are mounted on a common shaft. F_1 is the first and F_2 the second intermediate-frequency band filter; by means of a variable coupling the band width passing through these filters can be varied. The intermediate-frequency amplifying stage *M* is situated between the two filters. The intermediate-frequency alternating voltages are applied to the diode *D*, which also contains in the same glass-body the three-electrode valve of the low-frequency amplifying stage *L*. *Z* is the beat oscillator which generates an oscillation differing from the intermediate frequency by a specific (variable) frequency (usually 1000 cycles). The oscillation of the beat oscillator is also applied to *D*, so that at the exit of the rectifying stage an oscillation with the differential frequency (1000 cycles) is to be heard. *E* is the terminal stage with the output transformer.
The oscillating circuit *I* is tuned to the intermediate frequency and hence short-circuits any (disturbing) carrier wave emanating from a long-wave transmitter with a frequency equal to the intermediate frequency. By means of the switch *S* the automatic volume control reacting on all preceding valves *H*, *O* and *M*, can be switched on (left position) or replaced by manual control (right position). To generate the rectified output voltage for the automatic volume control a special detector *d* is provided. This is necessary because the diode *D*, being coupled to the beat oscillator *Z*, already furnishes an output voltage when no signal at all is received at the receiver, and would thus in this case already reduce the sensitivity of the receiver.

The Receiver

When crossing those areas of Asia sparsely provided with airports an aircraft must needs be equipped with a very sensitive receiver. The superheterodyne method adopted in the V.R. 18 equipment is particularly suitable for obtaining the high sensitivity required. A lay-out of the circuit employed (simplified) is shown in *fig. 4*. An octode (*O*) serves as a converter valve. It is preceded by a high-frequency amplifying stage (*H*). The intermediate frequency generated in the converter valve is again amplified (in *M*), then rectified (in *D*) and amplified once more in the low-frequency stage (*L*). A small beat oscillator (*Z*) is provided to render the continuous-wave signals audible, (since no audible frequencies per se are obtained from these signals after the rectifying stage). This oscillator generates oscillations with a frequency which differs only slightly from the intermediate frequency. If this frequency together with the intermediate-frequency signals is passed to the rectifying stage, the Morse signals become audible on the differential frequency between the two. The frequency of the beat oscillator can be regulated, so that the pitch of the Morse signals can be adjusted as required. This simplifies the separation of stations operating on wave-lengths close together. The receiver is rated for wave-lengths between 520 and 1300 m.

The apparatus, on a wave-length of 600 m, furnishes a power output of 10 milliwatts with a 0.75 μ-volt amplitude of the incoming signal [1]). This is roughly the maximum sensitivity which can be attained at present.

The sensitivity of the receiver can be regulated by hand, or an automatic volume control (see *S* in fig. 4) may be put into action with the aid of

[1]) Measured in accordance with the usual definition of sensitivity.

which the receiver adjusts itself continuously to a fairly constant output power and the volume can then be adjusted by hand to the required value. Volume control is particularly useful when approaching radio beacons, as without it the volume has to be continually readjusted.

A further requirement which has to be met in the receiving apparatus is the possession of a high selectivity. This feature is necessary to set up a reliable channel of communication in areas where air traffic is heavy, and is also of great value for flying in the tropics in order to reduce the effects of atmospheric interference. The circuit of the superheterodyne receiver permits a very high selectivity to be obtained in a very simple manner, for the intermediate frequency is constant so that a large number of invariable oscillating circuits can be tuned to it (see F_1 and F_2 in fig. 4). In some cases, however, a high selectivity is undesirable, particularly during wireless telephone reception (by cutting off the side bands, speech becomes distorted or even unintelligible) and particularly when picking up stations; in this case the wireless operator listens whether he is being called by any airport and must therefore listen as it were to all stations at the same time. To permit this to be done the selectivity of the apparatus is variable; the band width can be adjusted to 3.8, 5.5 and 7.5 kilocycles. The smallest band width is used for receiving continuous-wave telegraph transmitters, the medium width for telephony and tonic-train telegraphy, and the largest for picking up stations.

A photograph of the receiver with the chassis pulled out is reproduced in *fig. 5.*

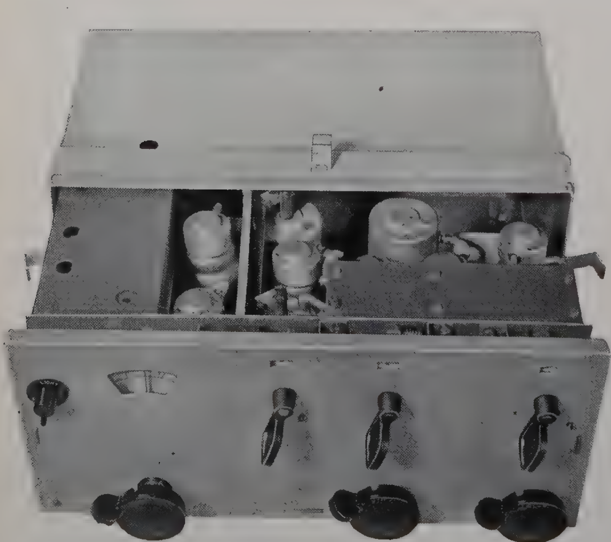

Fig. 5. V.O. 18 receiver with chassis pulled out. The housing and chassis are made of duralumin.

The Aerials

The Douglas air liners are equipped with a trailing aerial, i.e. a wire 60 m long which is loaded with a weight at the lower end and can be paid out during flight through a lead-through in the body of the aircraft. The paying-out and winding-in of the aerial is performed by a winch. An electrical counterpoise is provided by the metal fuselage of the aircraft.

In many cases a trailing aerial cannot be used. The time required to fly from one airport to another at a small distance, e.g. from Schiphol to Waalhaven, is only a few minutes at the high speeds attained by the Douglas machines. This time is not sufficient for paying out the aerial. Nevertheless, unbroken radio communication is necessary, for the aircraft must receive its landing instructions from the airport during flights. Moreover, it is desirable when landing to take in the aerial in good time and yet remain in communication with the airpost up to the last minute. For this purpose each machine is equipped with an additional aerial which is fixed permanently above the body. This is also naturally the only means whereby landing can be controlled from radio-beacons.

The Douglas air liners must be capable of flying in all weathers. Should they fly through storm clouds, a long trailing aerial will increase the danger of being struck by lightning. The aerial is therefore taken in and transmission and reception must then be maintained with the aid of the fixed aerial. To keep in communication with the airport, which in this case may be at a greater distance, and in spite of the lower radiation of the fixed aerial, which has only one quarter of the "effective height" of the trailing aerial, every care has been taken that the maximum possible portion of the available energy is radiated. In view of this, not only the trailing aerial but also the fixed aerial has, therefore, been carefully adapted to the amplifying stage, by introducing a special aerial-loading inductance and aerial coupling. A single manual movement of the switch provided is all that is required to change over from the trailing aerial to the fixed aerial.

Power Supply

Perhaps the nature of the power supply best brings out how far improvements in aircraft design have had a fundamental influence on the design of the aircraft wireless equipment. In the past an outboard generator was used with an auto-regulat-

ing air-screw (the anode voltage and the filament voltage had to be kept constant; in other words, the speed of the air-screw had to be independent of the "wind" velocity over a wide range, i.e. of the flying speed). As the flying speed was increased, which was achieved mainly by giving all and even the smallest components of the aircraft a stream-line design, the use of an outboard generator was no longer permissible in view of its high air resistance.

To act as a source of power for the whole equipment, the 12-volt starting battery is now used with the V.R. 18 set. The filaments are fed directly from the battery. The anode voltages for the transmitting and receiving valves are furnished by two converters which are driven from the battery. The anode voltage of the receiving valves must be properly smoothed and any interference eliminated. Formerly the necessary supply was therefore furnished by a dry battery; the converter now used for this purpose is of special design with a very low interference from the commutator brushes and in which all causes of interference have been most carefully eliminated by means of condensers and chokes.

The converter for the transmitting valves furnishes a uni-directional voltage of 500 volts at 300 milliamps and the converter for the receiving valves 200 volts at 40 milliamps. The starting battery is recharged during flight by a dynamo, which is driven from the aero-engines. Compared with the outboard generator, the battery offers the additional advantage that the machine can for some time continue to send out wireless messages from the ground, for instance after a forced landing.

Installation of Equipment

The transmitter with the associated converter is accommodated in a corner of the luggage cabin. It is suspended by shock-absorbing cables and is thus adequately protected against jolts and vibration. The receiver is set up on spring rubber supports in front of the operator's seat (*fig. 6*), together with the control box, on which are arranged, among other items, the Morse keys, various switches and the aerial ammeter. For night flying, dial illumination is provided, being capable of regulation and so placed that it does not interfere with the pilot's field of vision. The components of the transmitter and receiver are mounted on special chassis, which can be taken out separately. Like the boxes and the converter housings, these chassis are made of duralumin or aluminium in order to keep the weight as low as possible. The whole equipment (transmitter, receiver, two converters, winch and aerial lead-through, control box, switches, cable and telephone) weighs about 92 lbs.

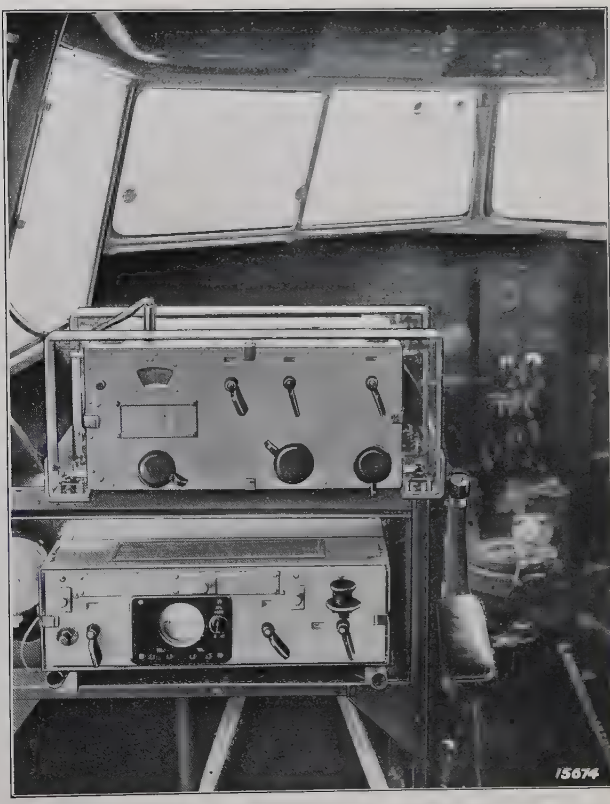

Fig. 6. Installation of the receiver (above) and the control box (below) in front of the wireless operator in the pilot's cabin of a Douglas air liner.

THE PHOTOMETRY OF METAL VAPOUR LAMPS

Summary. Following a discussion of the principles of photometry with regard to coloured light sources, an arrangement is described by means of which the luminous flux of gaseous discharge lamps are measured in this laboratory. Some results obtained in the photometric investigation of sodium and mercury vapour lamps with this apparatus are discussed in detail. The fundamental difficulties in the photometry of light-sources whose spectral intensity distribution does not correspond to that obtained with the standard, appear to be partiularly pronounced in measurements on the mercury vapour lamp. In conclusion, investigations are discussed which are being made in order to overcome the difficulties of heterochromatic photometry.

Introduction

As gaseous discharge lamps and in particular metal vapour lamps have become more widely employed, the photometric investigation of colourd light sources (heterochromatic photometry) became an urgent technical problem. An account is given below as to how the luminous flux of coloured light sources is measured in this laboratory, together with some special results obtained in measurements on sodium and mercury vapour lamps.

Before entering into details of these measurements, some of the principles of heterochromatic photometry will be briefly discussed.

Every photometric measurement is based on the comparison of brightness values. The particular difficulties encountered in photometric measurements on coloured light sources are due to the fact that the equality of brightness of two surfaces of different colour is determined by physiological means and therefore cannot naturally be reduced to a pure physical basis. Such determination depends entirely on the characteristics of the human eye. Particularly with very great difference in colour is it difficult to decide whether two surfaces A and B are equally bright. Various criteria of equivalent brightness are feasible and are indeed employd in practice as may be gathered from the following.

Direct Comparison of Brightness (Equality of Brightness Method)

Two light sources of different colour illuminate the two comparison fields of a photometer, viz, fields A and B. The positions of the light sources are so adjusted that the observer "sees" both fields illuminated equally bright. The criterion employed here yields a definite result only if the difference in colour is sufficiently small.

Step by step Method

If the difference in colour is so marked that a direct comparison is difficult, it is advantageous to introduce a series of intermediate stages, viz, the auxiliary fields A_1, A_2 ... A_n, which respective to their neighbours show such slight changes in colour that a direct comparison of brightness is possible between A and A_1, between A_1 and A_2, and so on, up to between A_n and B.

Application of the Flicker Photometer

In the flicker photometer, two illuminated surfaces whose brightness values have to be compared with each other, are projected into the field of vision alternately with a specified frequency. At a low frequency the field of vision appears to flicker in intensity as well as in colour. Beyond a certain frequency the colours merge into a composite colour, while with unequal intensities of the two surfaces a flicker in the brightness persists. At the lowest frequency at which the colour flicker has just disappeared, there exists a sharply defined adjustments of intensities at which the brightness flicker ceases also. The disappearance of brightness flicker may be considered to be a criterion for equality of brightness of the two surfaces.

It is important that, under the specific experimental conditions laid down by Ives [1]), the judgments regarding equality of brightness conforms to the following laws:

1) If brightness h_1 is equal to brightness h_2 and h_2 is equal to h_3, then $h_1 = h_3$ (transitive law).
2) If $h_1 = h_3$ and $h_2 = h_4$, then $h_1 + h_2 = h_3 + h_4$ (additive law). $h_1 + h_2$ is the sensation due to the sum of radiations yielding the sensations h_1 and h_2 respectively.

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1) H. E. Ives, Phil. Mag. 24, 149, 352 and 853, 1912. The angle of vision of the photometer field must be about 2 deg., corresponding roughly to the yellow spot of the retina. This point will be discussed again later on. Furthermore, the brightness must be at least 1 candle per sq. foot (at lower brightness values the Purkinje phenomenon is obtained owing to a displacement of the spectral distribution of ocular sensitivity). On the other hand it must not be too high, in order to avoid glare.

The transitive law is an inherent need, if it is desired to characterize a certain brightness by a single numerical value. But it is the additive law which offers a fundamentally simple method for a photometry, which is objective, i.e. independent of the eye of the observer.

Ocular Sensitivity Curves and Physical Definition of Brightness

The eye responds most sensitively to rays with a wave-length of approx. 5550 Å, so that of all radiations which produce an equal sensation of brightness a monochromatic (green) radiation of 5550 Å has the least energy. The ratio of the energy E_{5550} of this radiation to the energy of an equally bright radiation with a wave-length λ is a measure of the relative ocular sensitivity or luminosity factor V for the wave length λ:

$$V(\lambda) = \frac{E_{5550}}{E(\lambda)}$$

Various investigators have determined the spectral distribution of relative ocular sensitivity for a large number of observers [2]). An average of these results has been accepted as the international ocular sensitivity curve [3]).

By utilizing the additive law and the international ocular sensitivity curve an objective measure H can be introduced to represent the brightness of a radiation with arbitrary spectral distribution. The brightness of a radiation composed of light of different wave lengths λ_1, λ_2 ... can by the additive law be put proportional to the sum of the products of the luminosity factors $V(\lambda_1)$, $V(\lambda_2)$ ... and the corresponding radiation energies $E(\lambda_1)$, $E(\lambda_2)$ ... In practical units the definition of brightness so obtained is expressed as follows:

$$H = 621\, \Sigma V(\lambda_n)\, E_n \text{ lumens per sq. foot and solid angle unit.}$$

Here E is expressed in watts per sq. foot and solid angle unit (1 lumen per sq. foot and solid angle unit is equal to 1 candle per sq. foot).

In general the intensity is continually distributed throughout the spectrum, then the sum must be replaced by the integral:

$$H = 621 \int_0^\infty V(\lambda)\, E(\lambda)\, d\lambda \text{ candles per sq. foot} \quad (1)$$

2) K. S. G i b s o n and E. P. T. T y n d a l l, Bur. Stand. Scient. Papers, Nr. 475, p. 131, 1923.

3) Proc. International Commission of Illumination, 6th Meeting, Geneva, July 1925, pp. 67 and 232. Cf. also D. J u d d, J. O. S. A. **21**, 267, 1931.

Measurement of Brightness

For brightness measurements an observer should be required whose sensitivity curve coincides reasonably with the international curve. Experience has shown, however, that this condition is practically never fulfilled. A simple method has therefore been sought for selecting a small group of observers whose average results are of sufficient reliability. To do this it is absolutely essential to be able to determine in some way the difference between the sensitivity curve of an observer and the international sensitivity curve. The method proposed by I v e s and K i n g s b u r y [4]) for this purpose consists in determining the transmission factor of a yellow and a blue solution (aqueous solutions of potassium bichromate and copper sulphate of specified concentrations in vessels with an internal diameter of exactly 1 cm) for the light from a carbon filament lamp of specific temperature. The solution filters are so selected that their transmission factors are equal as measured with reference to the "international eye". The "yellow-blue ratio"

$$R_{yb} = \frac{\text{transmission of yellow filter}}{\text{transmission of blue filter}}$$

for an observer is then considered to be a measure for the deviation of his ocular sensitivity curve from the international curve. If the observers are so chosen that the average value of all "yellow-blue ratios" is unity, then, according to I v e s, even with a comparatively small number of observers the average value of the results obtained will be in satisfactory accord with the values which would be obtained on the basis of the international luminosity curve. It must, however, be borne in mind that this method, which up to the present has only been employed in photometric measurements on incandescent filament lamps in which the differences in colour are small, cannot be applied without reservation to metal-vapour lamps.

Description of the Photometric Apparatus

The apparatus [5]), which has been used for some years in this laboratory, has been designed specifically for the measurement of the luminous flux of direct-current and alternating-current gaseous discharge lamps. An integrating sphere is used in this apparatus which has been previously calibrated with a lamp giving a known flux. The

4) H. E. I v e s and E. P. K i n g s b u r y, Trans. Ill. Eng. Soc. 9, 795, 1914; **10**, 195, 1915.

5) P. C l a u s i n g, Physica, **2**, 731, 1935.

arrangement of the apparatus is shown in *fig. 1*, the inscriptions below indicating some details of the design. The use of the flicker photometer for measurements with the sphere did not appear desirable at the outset, as in measurements with

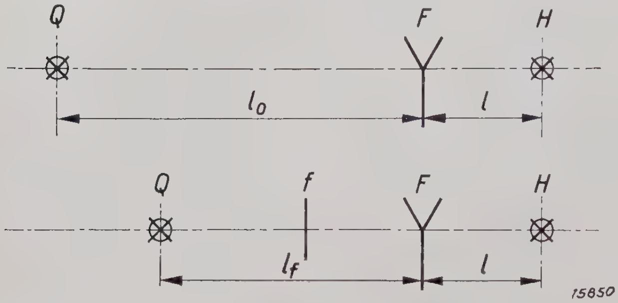


Fig. 2. Photometric arrangement for determining the transmission factor of the filter f.
Q = Standard lamp,
H = Auxiliary lamp for photometric comparison,
f = Filter,
F = Flicker photometer.

alternating-current lamps difficulties were anticipated as a result of interferences between the alternating-current and the flicker frequency. For this reason the equality of brightnes method was adopted and the chromatic difference kept as low as possible by equalising the colour of the comparison surface to that of the gaseous discharge by means of a filter [6]). The flicker photometer cannot, however, be dispensed with when using this arrangement, but serves for determining the transmission factor of the filter. Determination of the luminous flux of a gaseous discharge lamp thus requires three separate measurements, of which I and II need in principle only be carried out once for each type of lamp; these three are:

I) Calibration of the filter,
II) Calibration of the integrating sphere with a lamp of known luminous flux, and
III) Measurement of the luminous flux of a gaseous discharge lamp with the sphere by the filter method.

Calibration of Filter

Using a flicker photometer F (*scheme 2*) the

6) Similar methods have also been employed by other laboratories, cf. e.g. G. T. Winch, E. H. Palmers, C. F. Machin, B. P. Dudding, G.E.C.Journal **5**, No. 3, August 1934. H. Buckley, Ill. Eng. **27**, 118 and 148, 1934.

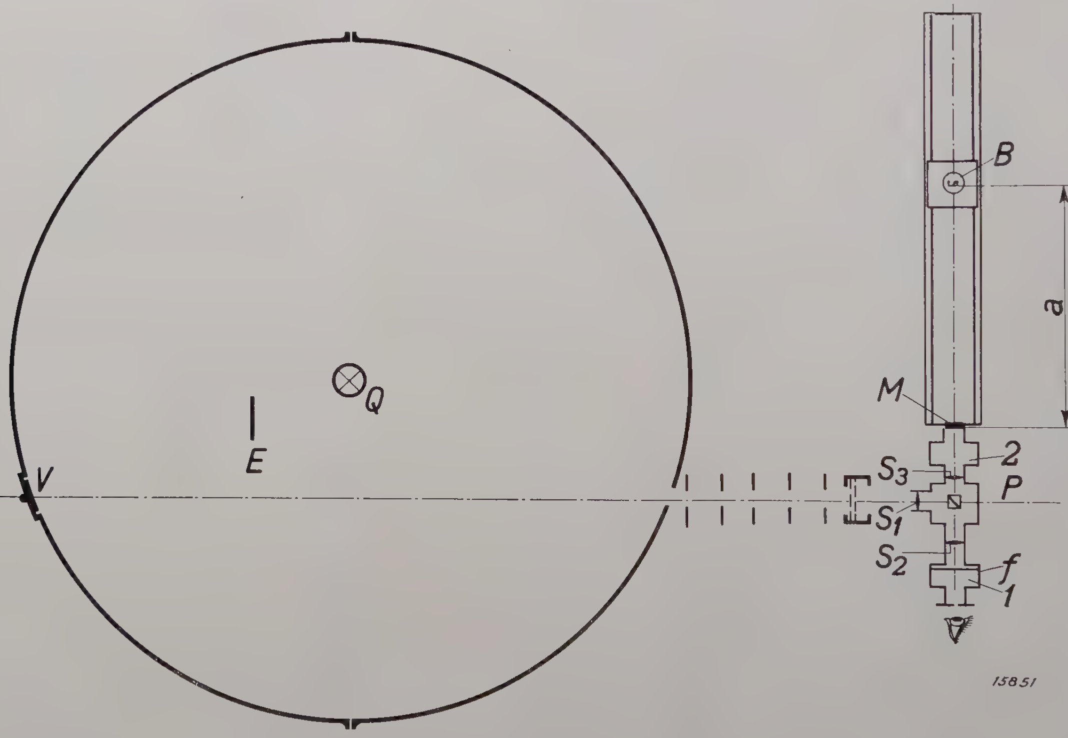


Fig. 1. Design of integrating sphere. The inner surface of the sphere is painted with a neutral grey colour, i.e. a colour whose coefficient of reflection is approximately independent of the wave length. Q = Standard lamp, V = Measured field of the sphere, E = Opaque, white screen, M = Opal glass, B = Band lamp for photometric comparison, P = Photometer cube, S_1 = Lens for obtaining an image of V on the focal point of S_2, S_3 = Lens for obtaining an image of M on the focal point of S_2, *1* and *2* = Filter boxes, f = Filter. The measurement of luminous flux by means of the integrating sphere is based on the fact that the illumination of every part of the surface which is screened against direct rays of the lamp (such as the measuring surface V here) is proportional to the total luminous flux. The illumination of V is determined by photometric comparison with the illumination of the opal glass M.

horizontal candle power of an incandescent lamp Q with a known luminous flux L is measured on a photometer bench, the lamp being later used for calibrating the integrating sphere. This measurement is carried out twice, viz, with and without

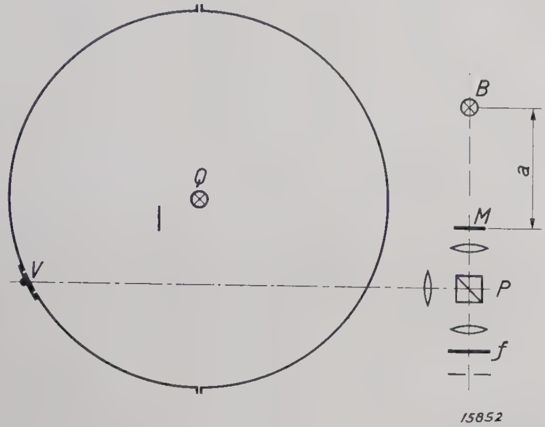


Fig. 3. Sketch of apparatus for calibrating the integrating sphere. The filter f is so placed that both the radiations from Q and B have to pass through the filter.

the filter f in the path of the light from Q. The transmission factor of the filter is calculated from the adjustments l_f and l_0 obtained, thus:

$$D = \left(\frac{l_f}{l_0}\right)^2$$

Calibration of the Integrating Sphere

The standard lamp Q is submitted to photometric measurement with the integrating sphere as shown in *fig. 3*. The distance a between the opal glass window M and the comparison lamp B is determined at which the surfaces of the Lummer-Brodhun photometer head, both viewed through the filter f, appear equally bright. (The comparison lamp B is a tungsten band-lamp.)

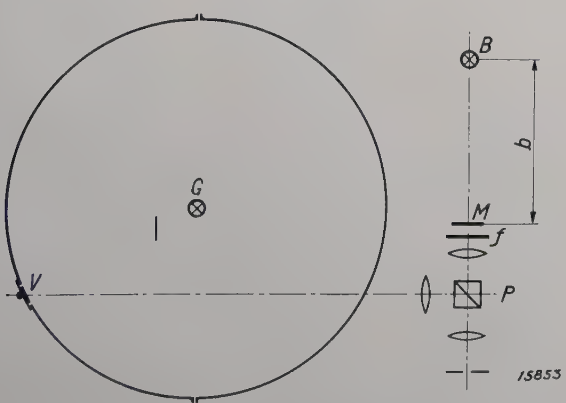


Fig. 4. Sketch of apparatus for measuring luminous flux. The filter f is so placed that only the light from B is filtered.

Measurement of Luminous Flux of Gaseous Discharge Lamps

The gaseous discharge lamp G is set up in the arrangement shown in *fig. 4* and compared photometrically with the comparison lamp B. The filter f is in a position different from that during calibration; it is so placed that the light from the integrating sphere does not pass through the filter. If the adjustment of equality of brightness yields a distance b between M and V the luminous flux of the gaseous discharge lamp is given by:

$$L_G = L \cdot D \cdot \frac{a^2}{b^2} = L \cdot \left(\frac{l_f}{l_0} \frac{a}{b}\right)^2 \text{ lumens.}$$

Filters

Filters of coloured gelatine are used, viz, Wratten filters. The best combinations found for various types of light are shown in *Table I*.

Table I. Best combinations of Wratten filters for adapting the radiations of a tungsten band lamp to various types of light.

Type of Light	Principal wave lengths in Å	Combinations of Wratten filters Nos.
Sodium light	5890 and 5896	23 A + 57
Mercury light	5461, 5770, 5790, 4358	38 + 51
Green mercury line	5461	62
Yellow mercury line	5770 and 5790	61 + 22

Table I also gives the filters used for measuring the luminous flux of individual mercury lines alone. In this case the mercury light must naturally also be filtered. The arrangement shown in fig. 3 (rather than that shown in fig. 4) must therefore be used in these measurements. The absorption of the yellow or green mercury line by the filter is determined in a separate measurement, using a photo-electric cell [7]).

Results

The adaptation of the filtered radiation of the comparison lamp to the colour and spectral distribution of the sodium vapour lamp is in general very satisfactory. Photometric measurements of mercury vapour lamps are, however, more difficult, mainly because the colour of the light, emitted from these lamps varied considerably during the rapid technical progress which has been made in

[7]) The determination of the absorption coefficients with the photo-electric cell is of course only permissible when the radiation undergoes no change in spectral distribution as a result of absorption. This condition is fulfilled for instance on filtering monochromatic light.

these lamps in the course of the last few years. In addition the avalable filters for adapting the spectral distribution of the comparison lamp to that of the mercury lamp are not so suitable as that for the sodium lamp.

To test the reliability of measurements, the luminous flux of the yellow and green lines was separately determined for a number of mercury lamps in addition to the total flux. The sum of the values obtained for yellow and green radiation should agree to within a small percentage with the total flux, as the blue radiation contributes very little to the total light. *Table II* gives some results which appear quite satisfactory.

Table II. Luminous flux (lumens) of green and yellow lines separately and total flux of mercury lamps.

Lamp	Green line	Yellow line	Green + yellow	Total	Difference per cent
1)	9085	10350	19435	20600	—5.6
2)	3530	3456	6986	7187	—2.8
3)	2075	2190	4265	4320	—1.3
4)	5285	5640	10925	11030	—1.0
5)	3195	3214	6409	6575	—2.5
6)	7948	9209	17157	12800	—3.6
7)	3300	3310	6610	6850	—3.5
8)	5010	5275	10590	10590	—2.5
9)	6610	6610	13220	13800	—4.3

More protracted measurements and a change in the group of observers have, however, shown that photometric measurements were not always reproducible owing to the inadequate chromatic adaption. *Table III* shows that measurements made by the two observers R and K, which were in satisfactory agreement in February, were subject to a marked deviation in August. The second column gives the results obtained by the same observers when using a flicker photometer instead of the equality of brightness method. In this case

Table III. Luminous flux (lumens) of mercury lamps, measured by two observers in February and August.

Lamp	Date	Observer	Filter method	Difference %	Flicker method	Difference %
I	February	R	7940	1.0	7000	1.7
		K	7860		6860	
II	August	R	9140	8.4	8290	1.2
		K	8370		8190	

The results obtained by the two observers using the filter method are in very good agreement in February, but differ considerably in August. Moreover, except for observer K in August, there is a marked difference between the results obtained by the filter method and with the flicker photometer.

there is no abrupt difference in the results obtained by the different observers. From this it may be concluded that the sudden anomaly is not due to a change in the properties of one observers' eye.

Investigations are being prosecuted in three directions with the goal of improving the reproducibility of the measurements.

Reduction of the Photometer Field

As Ives (cf. footnote [1])) has shown, the results obtained with the flicker photometer are only reliable when the angle of vision does not exceed 2 deg. With direct comparison also a systematic difference is observed between the results obtained with angles of vision of 6 deg. and 2 deg. respectively. As to be expected, on reducing this angle the difference between the equality of brightness method and the flicker photometer diminishes. *Table IV* gives the results of measurements carried out all on the same lamp with angles of vision of 6 deg. and 2 deg., and with an equality of brightness photometer and a flicker photometer respectively.

Table IV. Luminous flux (lumens) of three mercury lamps, measured by the flicker method and the equality of brightness method with angles of vision of 2 deg. and 6 deg.

Lamp	Observer	Flicker method Angle of field [8]) 2 deg.	6 deg.	%age difference	Equality of brightness method Angle of field 2 deg.	6 deg.	%age difference
A	V	6875	6745	+1.9	7140	7850	+9.9
	R	6955	7000	+0.6	7475	7940	+6.2
	K	6925	6860	—0.9	7440	7860	+5.6
B	V	8245	8245	0.0	8635	9385	+8.7
	R	8550	8280	—3.1	8965	9615	+7.2
	K	8300	8220	—1.0	8830	9320	+5.5
C	V	8195	8175	—2.4	8675	9485	+9.3
	R	8475	8375	—1.2	9130	9595	+5.1
	K	8290	8320	+0.4	8940	9440	+5.6

On using the equality of brightness method, it was found that a decrease of the field of vision from 6 deg. to 2 deg. causes a considerable reduction in the observed values of luminous flux (particularly with observer V). With the flicker photometer the influence of the angle of vision is less marked. The difference between the results obtained with the flicker photometer and the equality of brightness method is certainly reduced by diminishing the angle of the photometer field, but is not entirely eliminated.

[8]) The flicker photometer with 6 deg. angle of vision (Bechstein type) has a divided field; the inner field of 2 deg. flickers in opposition to the outer field. The observation that (contrary to the statement of Ives) the results obtained with the 2 deg. and 6 deg. fields are practically the same is perhaps due to the fact that the eye of the observer is fixed on the inner field only.

Application of the Flicker Photometer also to A.C. Lamps

In spite of interferences between the brightness fluctuations of A.C. lamps and the flicker frequency, the measurements with the flicker photometer were found reproducible beyond all expectations (see *Table V*). Since, however, as indicated in Table III, three of the four measurements using the equality of brightness method yielded higher brightness values for the mercury lamp than the flicker photometer, the question arose as to whether systematic errors occurred in measurements on A.C. lamps when using the flicker photometer. This point was investigated by means of a light-source flickering with a 100-cycle frequency, which was produced by rotating a sector disc in front of a direct-current lamp. It was found that between the photometrically measured transmission factor of the sector disc and the value calculated from the dimensions, non-systematic errors not exceeding 4 per cent occurred, so that in this respect there is no serious objection to the use of the flicker photometer.

Table V. Reproducibility of measurements on alternating-current lamps with the flicker photometer.

Date of measurement	Sodium Lamp 70 watts	Sodium Lamp 50 watts	Mercury Lamp 500 watts	Mercury Lamp 400 watts
	lumens	lumens	lumens	lumens
11.10.35	—	—	23400	15580
15.10.35	—	—	23400	15600
4.11.35	3400	2020	—	15650
16.11.35	—	2080	—	—
30.11.35	3450	2110	23670	15940
4.1.36	—	—	23510	—
14.1.36	3410	2015	—	15690
24.1.36	—	—	—	15020
26.2.36	—	—	23300	—

The values for the luminous flux of one and the same lamp obtained on different days agree within the limits of the accuracy of measurement, which is a few per cent.

Physical Measurement of the Luminous Flux

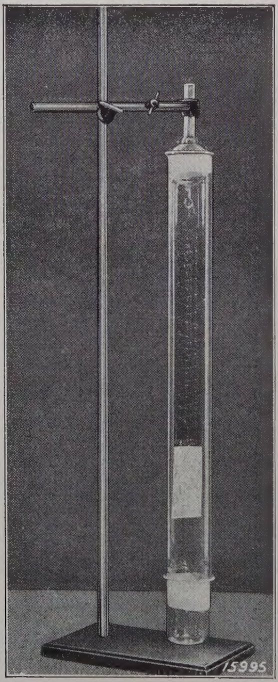
The luminous flux is defined on a physical basis by equation (1), indicating that it is fundamentally possible to determine the value of this magnitude by purely physical means. For this purpose a light-sensitive apparatus is required which reacts to radiation of the wave length proportional to $E(\lambda)\ V(\lambda)$ (e.g. electrically). Furthermore, the reactions to raditions of different wave lenghts must be additive. The construction of such an apparatus using a photo-electrical cell and filters has been described in detail by König[9]). The practical application of this objective method is undoubtedly highly desirable because with every subjective method it is very difficult to determine in how far results obtained by a limited number of observers conform to the results based of international luminosity curve. There are, however, certain technical difficulties, since severe requirements have to be met as regards the absolute constancy of the properties of the photo-electric cell and the filters. It may, however, be expected that these difficulties will be overcome enabling the physical measurement to be regarded as the most suitable method of the future.

Compiled by G. HELLER.

9) H. König, Helvetica Physica Acta 4, 427 and 433, 1934.

A very sensitive spring balance

It has been known since ancient times that forces and in particular weights, can be measured by the elongation they produce in a spiral spring. Spring balances based on this principle offer various advantages, such as extreme simplicity of construction, the possibility of taking continuous readings, etc. Moreover, by making the spiral spring of very thin quartz wire (quartz being very suitable on account of its small elastic after-effect and its chemical inertness) it is possible to obtain very high sensitivities, as a result of which these spiral springs can be employed for numerous purposes and particularly for micro-investigations [1]). Spring balances of the type described below are used technically, for instance, in gas analysis, for checking the liberation of gas from metals in high-vacuum tubes. They may futhermore serve for testing the amount of moisture absorbed by textiles and paper, for testing the spread of lubricants, and in general for measuring very small forces or weights.



For the study of gases one frequently makes use of the adsorption phenomenon whereby the gas adheres to the surface of a suitable solid substance. When this adsorptive substance is suspended from the quartz spring in a space into which the gas is introduced, the increase of weight of the adsorbing medium resulting from the adsorption of a certain quantity of gas causes an elongation of the coil which can be read accurately to within 0.01 mm by means of a cathetometer.

The sensitivity of a spring balance of this type, i.e. the elongation per unit weight suspended from it (cm per mg) increases with the thinness of the quartz wire, the width of the spiral and the number of turns it possesses. With a thickness of wire of 70μ, a spiral of 2.5 cm diameter and 10 turns, a sensitivity of 1 cm per mg (and over) has been obtained here. The minimum elongation of 0.01 mm measurable with the cathetometer thus corresponds to a weight of 1/1000 mg.

In order to be able to utilise this high sensitivity, however, care must be taken that the initial load on the quartz coil (i.e. the total weight suspended from the coil) is made very small. In similar apparatus used elsewhere the initial load ranged from 500 to 1000 mg, so that a coil with a sensitivity 1 cm per mg would become extended by from 5 to 10 metres as a result of this load! For this reason a new method has been elaborated in which a few milligrams (this small amount being sufficient) of the adsorbing medium is deposited by volatilisation on a mica foil 5 μ in thickness and $4 \times 6 = 24$ sq. cm in area. Deposited layers of this type have an active surface which is many times (e.g. 50 times) larger than the geometrical surface. The mica foil with the deposited surface-layer is suspended from the quartz coil (see fig.), and as it weighs only about 25 mg the initial elongation is 25 cm.

One particular problem in making the balance is the manner of preparing the quartz coils. This operation is performed automatically on a coiling machine in which a quartz cylinder is used as a core. If wires are used whose thickness does not vary by more than 5%, very uniform coils free from stresses can be obtained by this method. The quartz wires are prepared by a special process and their thickness is checked with the microscope.

C. J. Dippel.

[1]) See for instance J. W. MacBain and A. M. Bakr, J. Am. chem. Soc. 48, 690, 1926.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN [1])

No. 1050: J. H. de Boer and C. F. Veenemans: Adsorption of alkali metals on metal surfaces. VI — The selective photo-electric effect (Physica **2**, 915-922, Nov. 1935).

Alkali atoms are primarily adsorbed at metal surfaces in the form of ions. From a covering fraction Θ upwards, atoms are adsorbed and these take up positions immediately adjoining an ion. At covering fractions $\geq \Theta_m$ atoms are also adsorbed which are not linked directly to an ion but to other alkali atoms. The authors in this paper investigate the adsorption of sodium by tungsten. With low covering fractions, ordinary photo-electric emission of the tungsten takes place which is intensified by the electrical double-layer formed by the sodium ions. At higher covering fractions ($> \Theta_i$) selective photo-electric emission of the adsorbed ions forms an appreciable part of the photo-current. Those atoms which are bound next to the ions ($\Theta_i < \Theta < \Theta_m$) emit electrons only at comparatively short wave-lengths in the ultra-violet. But as soon as $\Theta > \Theta_m$ a selective photo-electric effect occurs at higher wave-lengths. This is due to the adsorbed atoms which are located near other atoms and are less loosely linked in such positions, but on transition to ions by photo-ionisation become more firmly bound than in the neighbourhood of another ion. At the end of the paper a summary is given of parts I tot VI.

No. 1051: J. A. M. van Liempt: Die Dampfdrucke der Metalle und ihre Verdampfungsgeschwindigkeit im Vakuum (Rec. Trav. chim. Pays-Bas **54**, 847-852, Nov. 1935).

For regular crystals formulae are deduced expressing the rate of vaporisation in vacuo as a function of the temperature, for the vapour pressure as a function of the temperature, and for the heat of vaporisation at the temperature of vaporisation. The rates of vaporisation and vapour pressures for different metals are in satisfactory agreement with the values calculated from these formulae.

No. 1052: J. van Niekerk: Changes in the sensitivity of rachitic rats for vitamin D (Arch. néerl. de physiologie de l'homme et des animaux **20**, 477-480, Oct. 1935).

The anti-rachitic dose of a vitamin D preparation of Reerink and van Wyk determined by the author before the introduction of standard preparations, appeared very small to van Harreveld compared with the activity of the same preparation in international units estimated subsequently by the author. The latter now explains this difference as being due to a diminution of sensitivity of his strain of experimental animals; this diminution was concluded from a long series of control calibrations with international standard preparations.

No. 1053: E. J. W. Verwey and M. G. van Bruggen: Structure of solid solutions of Fe_2O_3 in Mn_3O_4 (Z. Kristallogr. **92**, 136-138, Oct. 1935).

By means of X-rays the authors have investigated the crystal structure of a series of solid solutions of Fe_2O_3 in Mn_3O_4. It was found that the tetragonal structure of Mn_3O_4 (Hausmannite) with increasing Fe_2O_3 content gradually passes over into the cubic spinel structure. The axial ratio, which is 1.16 with M_3O_4, assumes a value of 1.0 with an atomic ratio of Mn: Fe = 3 : 2, so that from this composition onwards the structure can no longer be distinguished from one with cubic symmetry.

No. 1054: J. A. M. van Liempt and J. A. de Vriend: Die Schmelzzeit von Schmelzsicherungen II (Z. Phys. **98**, 133-140, Nov. 1935).

By means of a high-vacuum cathode-ray oscillograph, the times of fusion of a number of fusible cut-outs were determined at different short-circuit current values, which were up to 20 times the limiting current ratings of the fuses. In the case of 2-25 amp fuses, it was found in accordance with previous investigations that the product of the time of melting and the square of the applied short-circuit current was fairly constant for each type of fuse. The constant is in satisfactory agreement with the values calculated theoreti-

[1]) Reprints of these papers may be obtained on application from Philips Laboratory, Kastanjelaan, Eindhoven, Holland.

cally. Finally 6-amp fuses were loaded with the limiting current of 6 amps for half an hour and in this pre-heated state the short-circuit current was applied. The time of fusion was then found to be reduced to half the initial value.

No. 1055: E. J. W. Verwey: Electrolytic conduction of a solid insulator at high fields. The formation of the anodic oxide film on aluminium (Physica **2**, 1059-1063, Dec. 1935).

To account for the formation of the crystalline oxide film during the electrolytic oxidation of aluminium, the author suggests the following mechanism: Under the action of the powerful field, Al ions are drawn into the initially formed surface oxide film composed of close-packed oxygen ions, wherein electrolytic conduction then takes place. As the author has already shown the product obtained is γ'-Al_2O_3, a cubic face-centred oxygen-ion lattice in which the Al^{3+} ions are distributed statistically, viz, 70 per cent at the octahedral positions and 30 per cent at the tetrahedral positions. The unoccupied positions then serve as "intermediate lattice positions" in the sense of Frenkel's theory of electrolytic conduction in a solid. The electrical conductivity calculated is of the same order of magnitude as the measured values.

No. 1056: W. G. Burgers and J. L. Snoek: Lattice distortion and coercive force in single crystals of nickel-iron-aluminium (Physica **2**, 1064—1074, Dec. 1935).

The phenomenon of hardening as a result of the tendency for the precipitation of molecules from the super-saturated solid solution is investigated by X-rays and magnetically on single crystals of Ni-Fe-Al alloys, obtained by unilateral cooling. The γ-phase which should be precipitated, does not occur under normal conditions of hardening but only on heating to above 1000 deg. C. During hardening characteristic changes in the X-ray diffraction lines of the α-phase are observed. The authors assume that in the original crystal lattice nuclei of varying composition are formed which possess a different lattice distance and hence produce stresses in their environment. On increasing or enlarging these nuclei, the coercivity increases to a maximum, after which it diminishes again. This may be explained either by a plastic deformation of the stressed material which in this way regains its structure or by the assumption that the precipitation of the γ-phase does actually take place, the unstressed lattice then being re-established during transformation.

No. 1057: E. J. W. Verwey: Eenige vlakkengecentreerde roosters met onvolledig gerangschikte kationen (Chem. Wbl. **32**, 721-726, Dec. 1935).

The structure of many crystal lattices is determined by the anions which are considerably greater than the cations. In the case of the crystals under consideration here the anions form a regular face-centred lattice; on the other hand the cations are distributed statistically over the available tetrahedral and octahedral positions. The various types of these "intermediate structures" differ in the degree of random arrangement of the cations owing to their thermal mobility, or in the presence or absence of unoccupied positions in the statistical distribution (cf. also Nos. 1039 and 1040).

No. 1058: A. Bouwers: Die Leistungsfrage bei Röntgenaufnahmen (Röntgenpraxis **7**, 779-780, Nov. 1935).

In this paper the commonly-held opinion is opposed that in order to improve the definition of the X-ray pictures the power of X-ray tubes must be raised. This raise at the present could only be achieved by enlarging the radiating focus whereby the geometrical lack of definition U_g of the radiograph would increase. Though the lack of definition caused by the motion of the object, U_b, would diminish (the increased power enabling a shorter time of exposure), the definition would not be much improved, since the optimum definition in a radiograph is always obtained when $U_b = U_g$. From these considerations the author concludes that by shortening the time of exposure the definition of the picture will only be increased, when this shortening is possible (owing to more sensitive photographic material) with a reduced power of the X-ray tube.